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(54) **APPARATUS, SYSTEMS, AND METHODS FOR REMOTELY DIMMING LIGHTS**

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H05B 37/02 (2006.01)

(52) **U.S. Cl.**
CPC **H05B 37/0272** (2013.01); **H05B 37/0227** (2013.01)

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37/029; H05B 1/025; H05B 33/0806; H05B 33/0842; H05B 33/086; H05B 33/0863; H05B 33/0866; H05B 37/0236; H05B 39/04; H05B 41/14; H05B 1/0205; H05B 33/0893; H05B 37/00; H05B 37/0209; H05B 37/0254; H05B 37/03; H05B 39/041; H05B 39/044; H05B 39/048;

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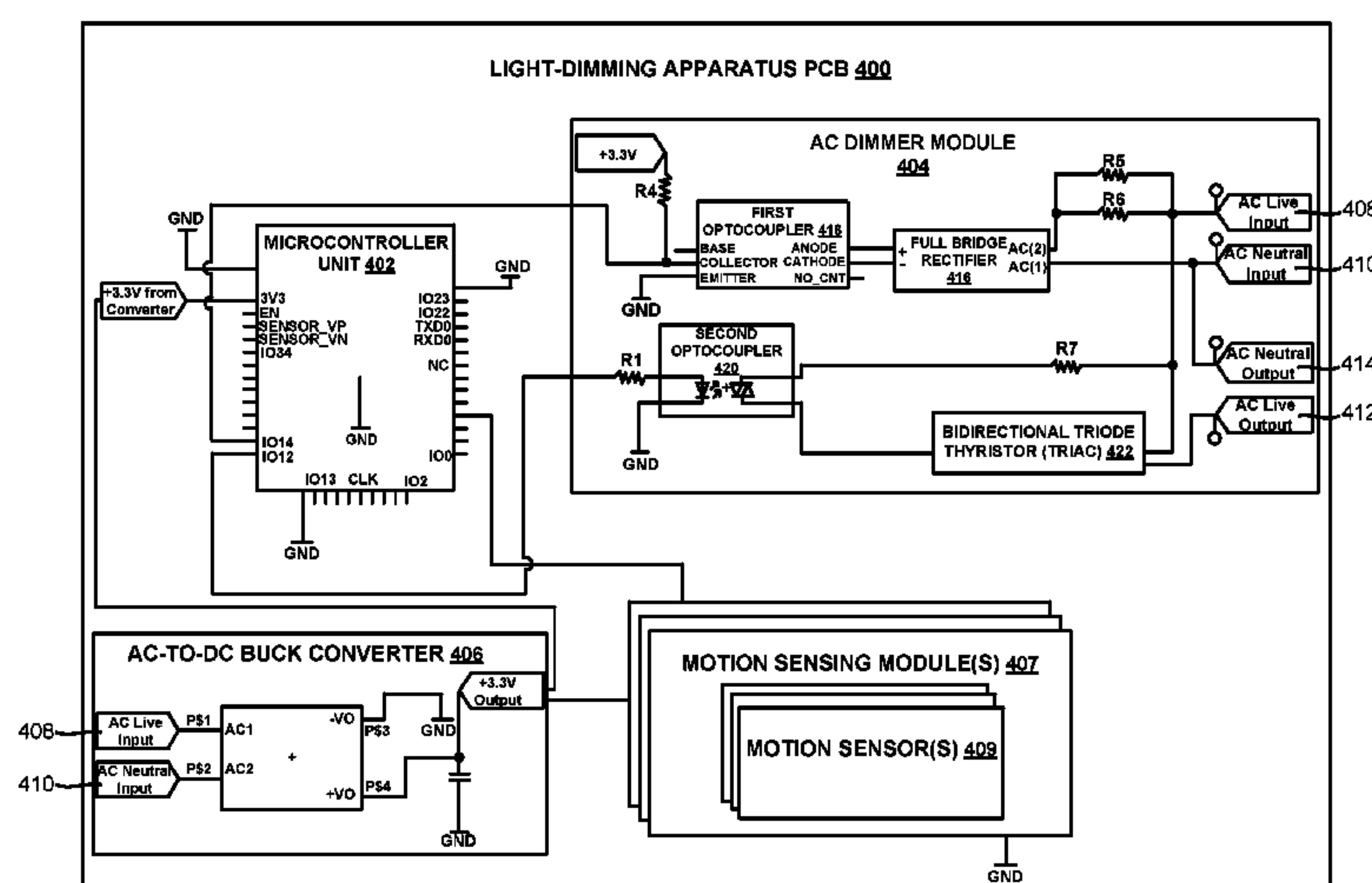
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(57) ABSTRACT

Apparatus, systems, and methods for remotely dimming lights are disclosed. In one embodiment, a light-dimming apparatus for placement within a lighting enclosure of a lighting fixture is disclosed. The light-dimming apparatus can comprise an AC live input terminal, an AC neutral input terminal, an AC live output terminal, an AC neutral output terminal, a dimmer module, one or more motion sensing modules, and a microcontroller unit comprising a plurality of wireless communication modules, and one or more processor cores. The one or more processor cores can be programmed to execute instructions to receive a dimming command from another device via at least one of the plurality of wireless communication modules, receive zero-crossing signals from the dimmer module, and transmit switching signals to the dimmer module to modulate the power supplied to the lighting load to dim the brightness of the lighting load.

20 Claims, 9 Drawing Sheets



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CPC H05B 39/086; H05B 39/088; H05B
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See application file for complete search history.

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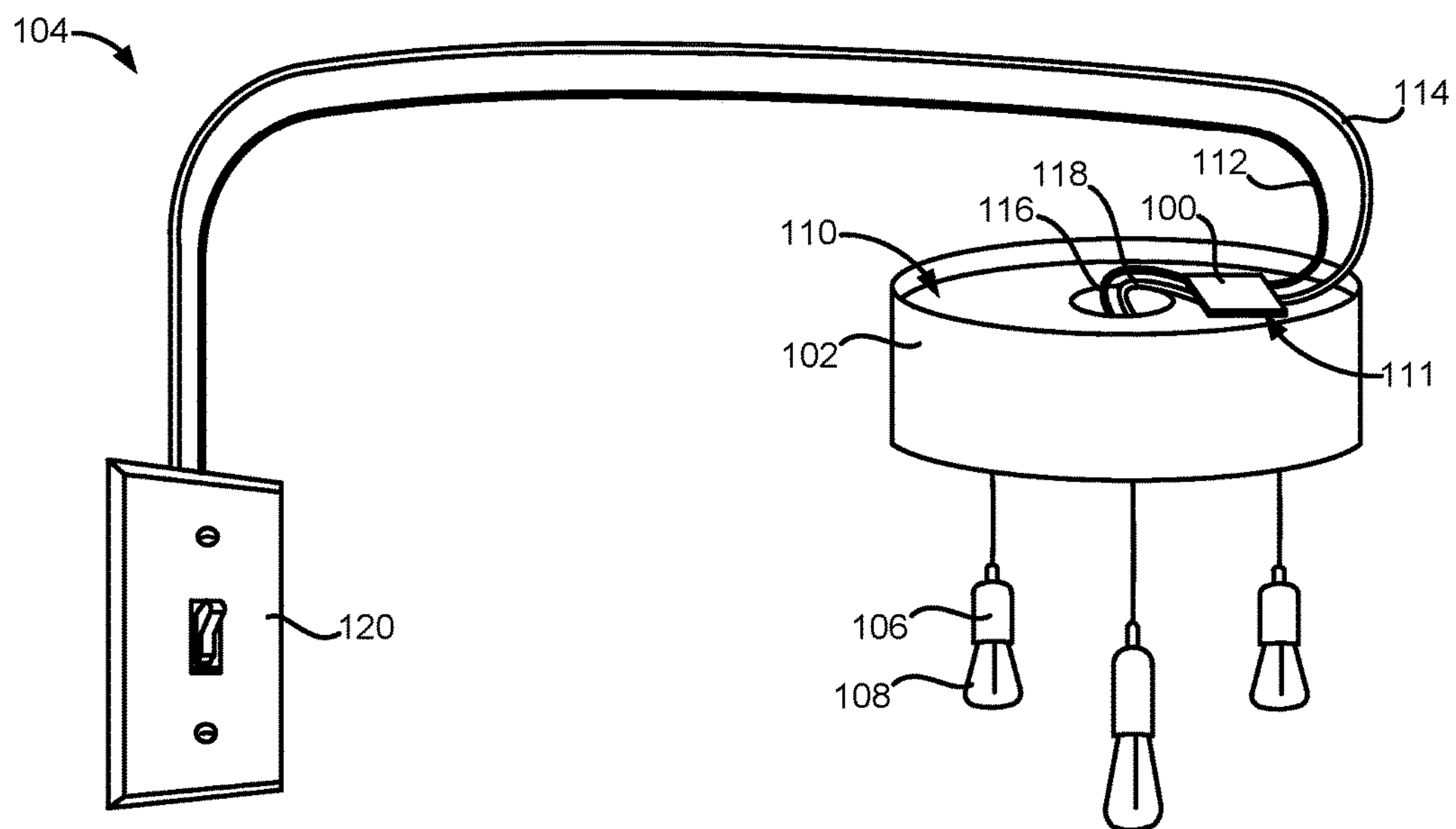


FIG. 1A

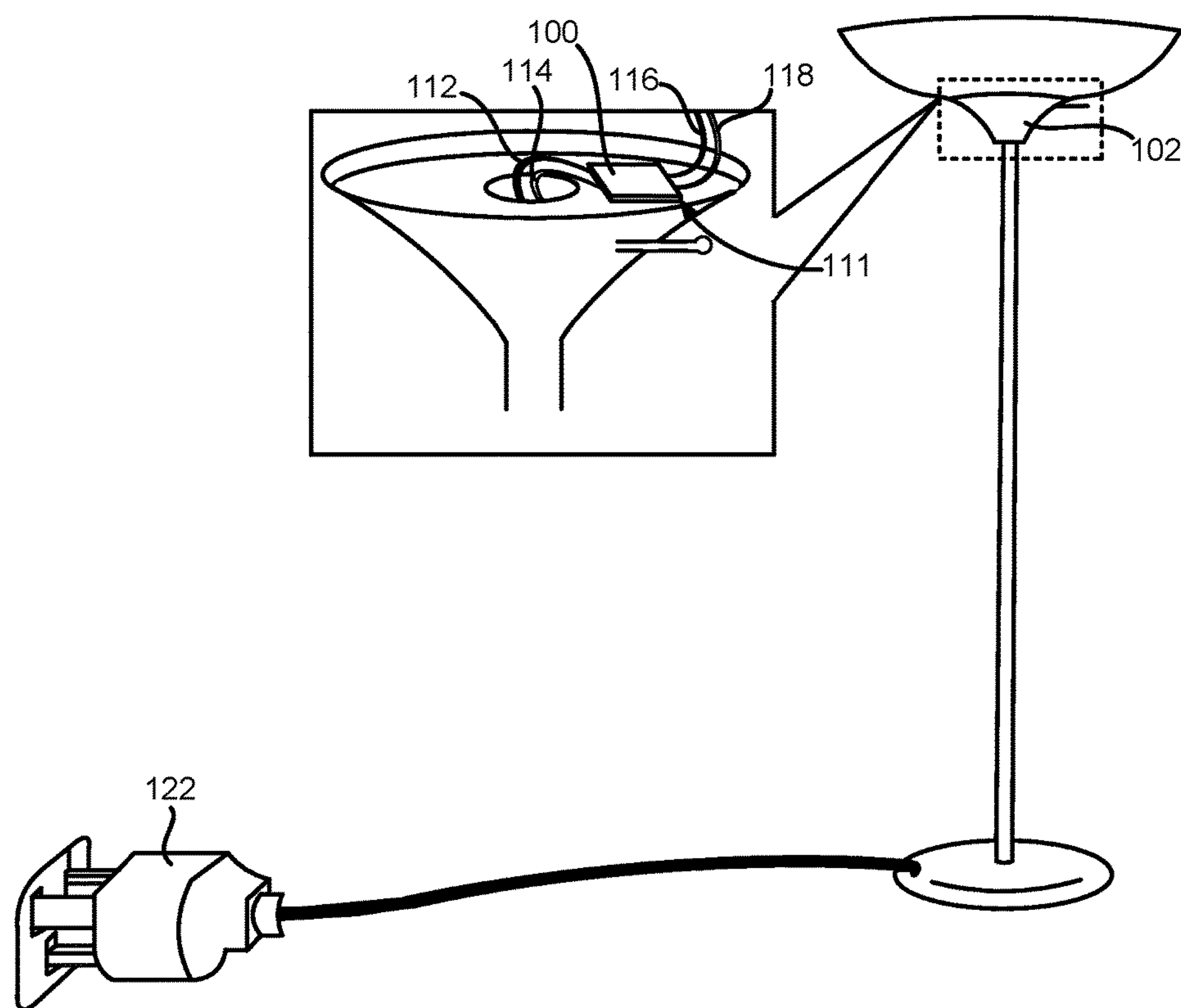


FIG. 1B

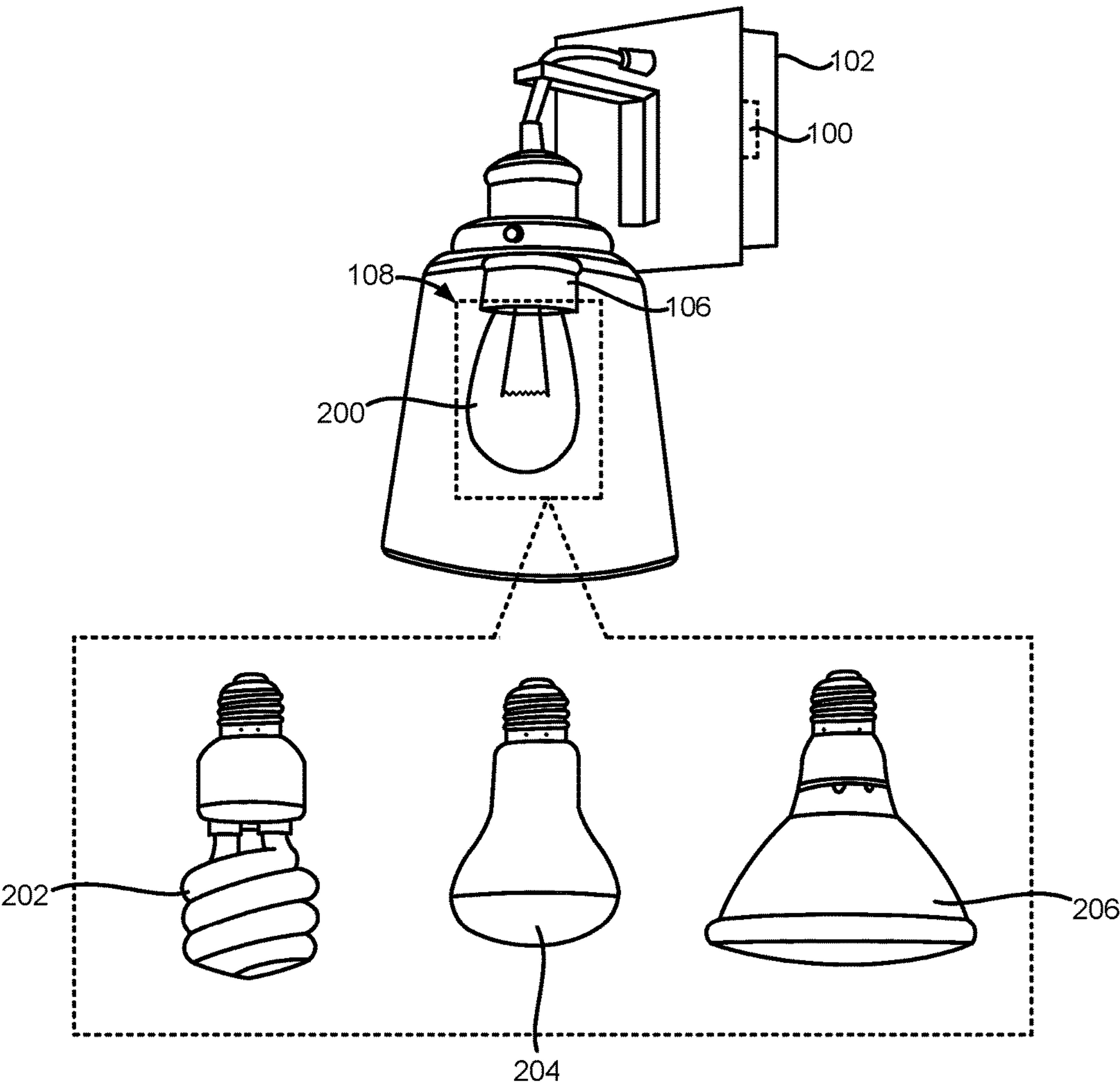


FIG. 2

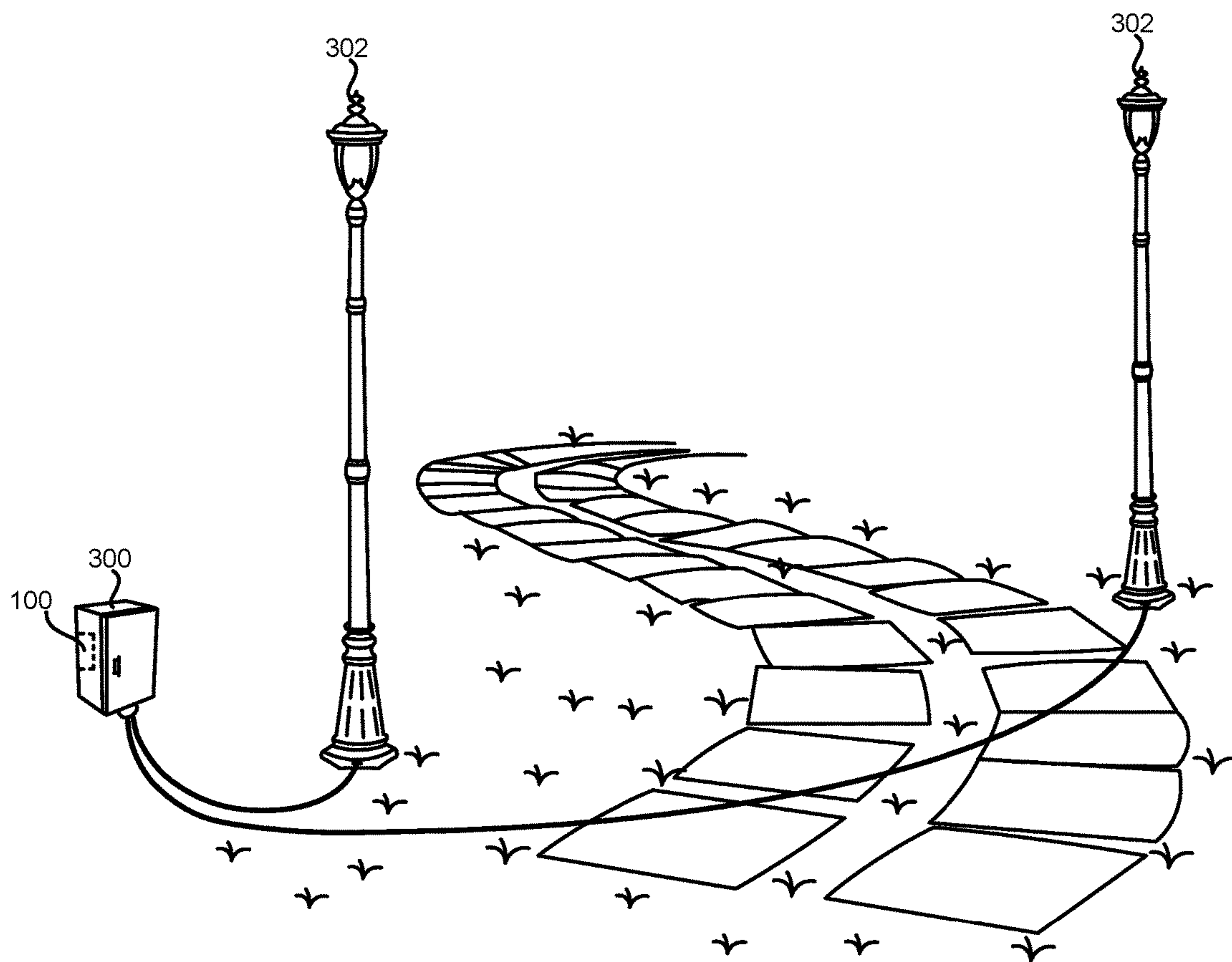


FIG. 3

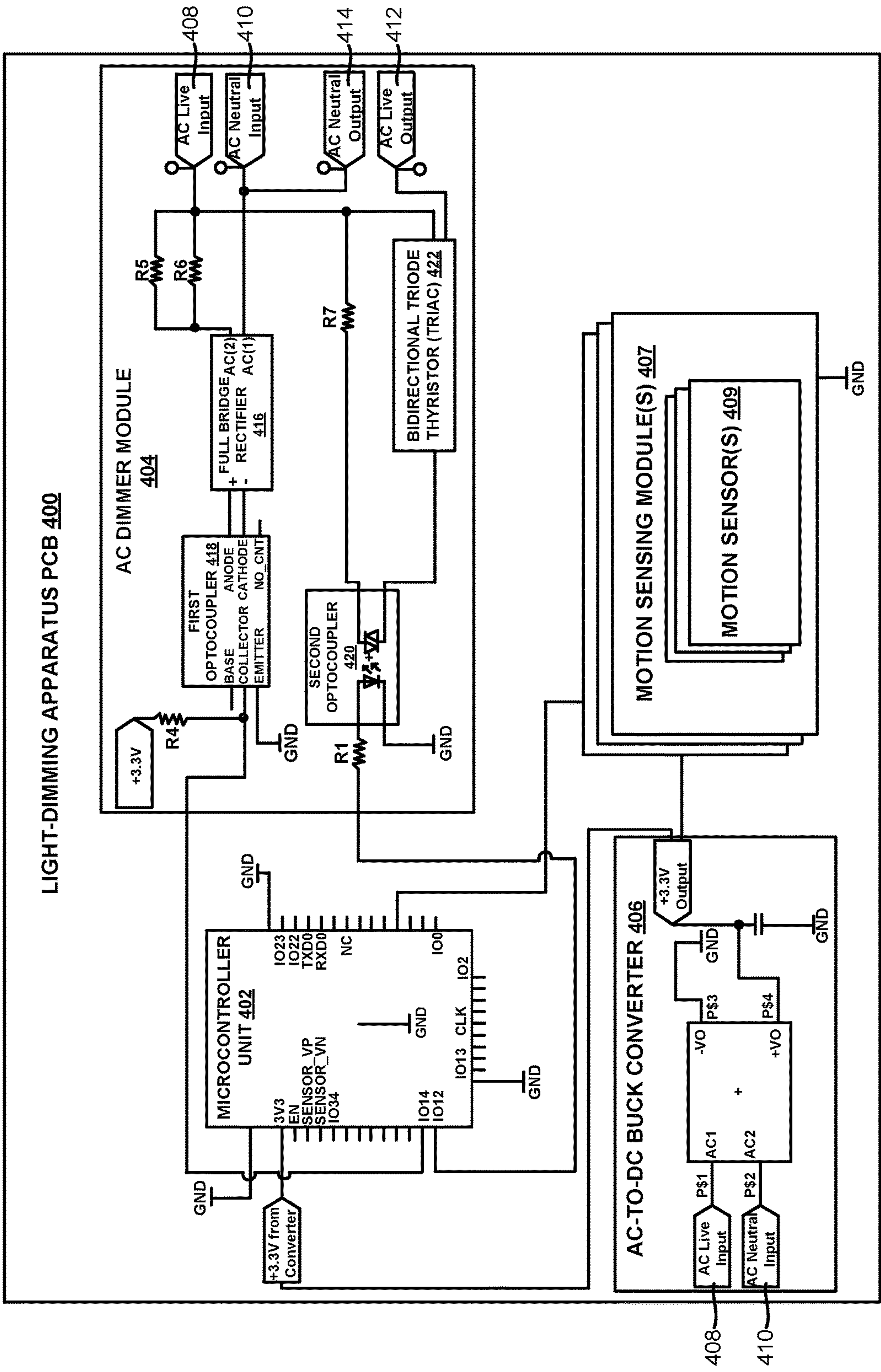


FIG. 4

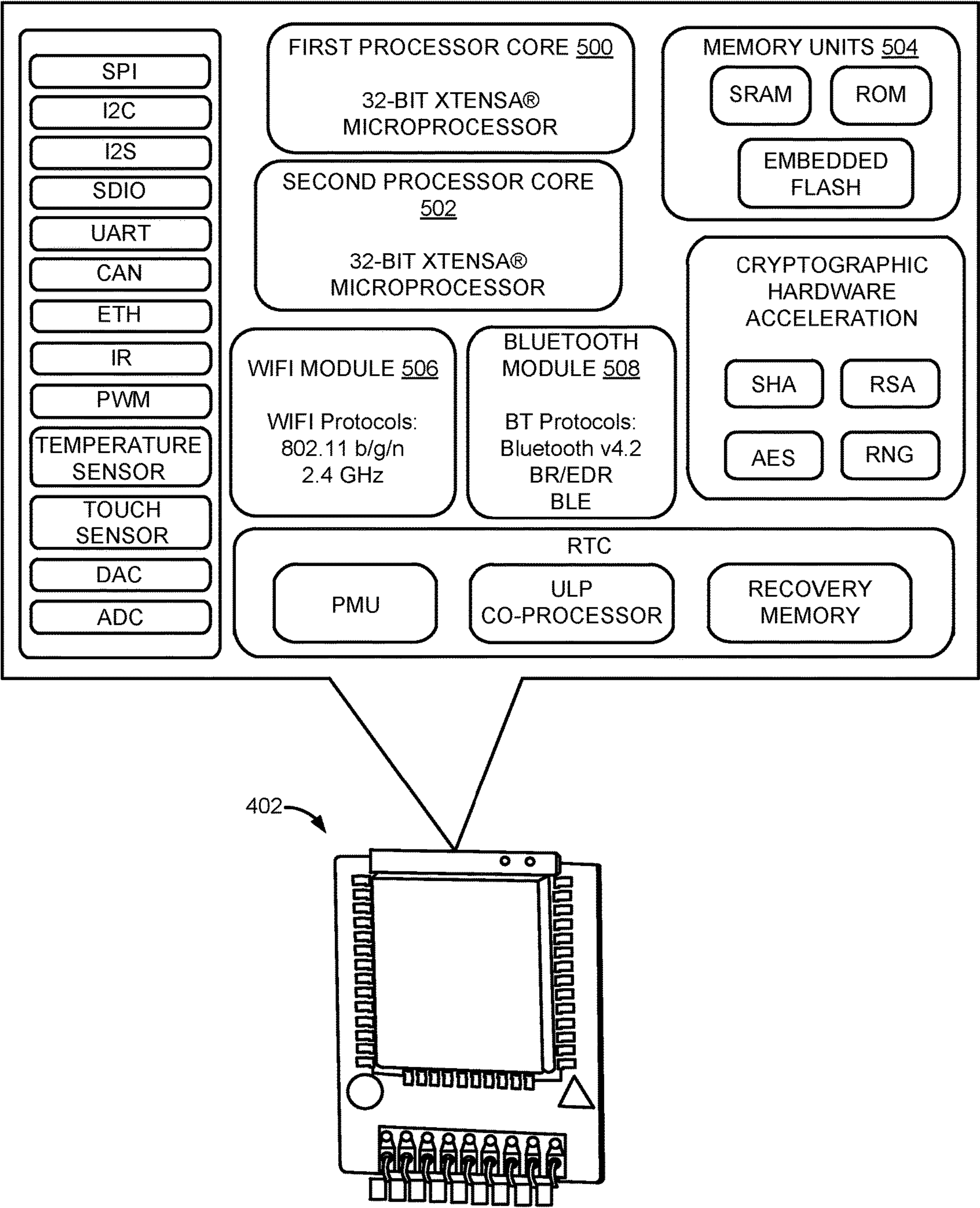


FIG. 5

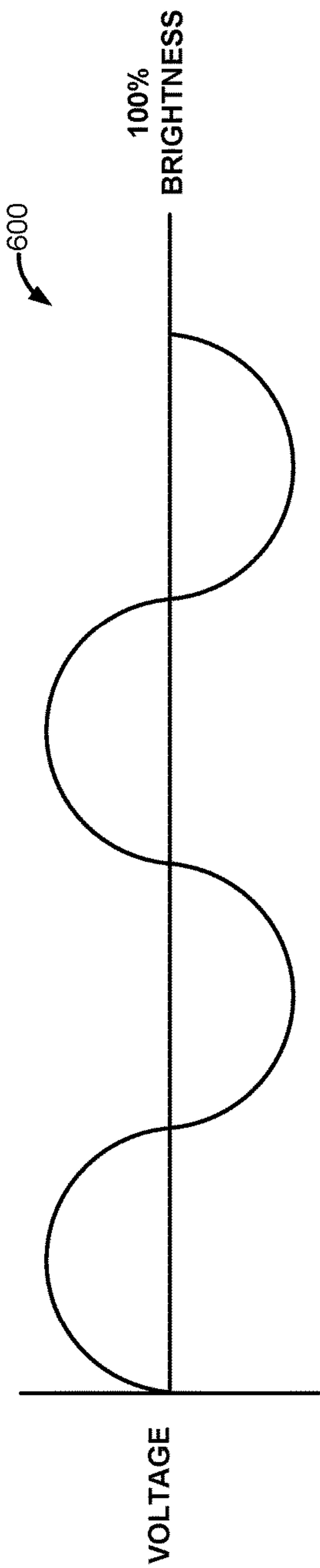


FIG. 6A

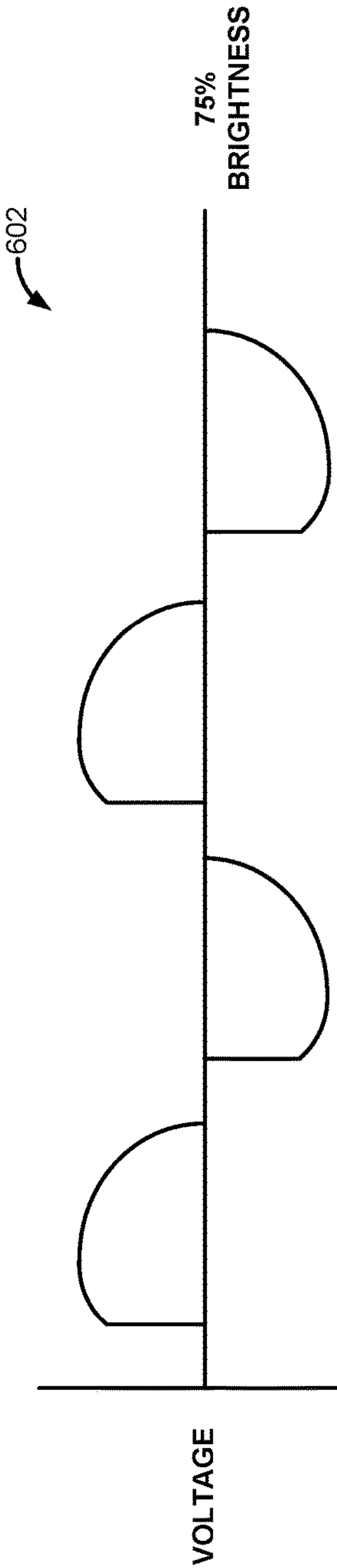


FIG. 6B

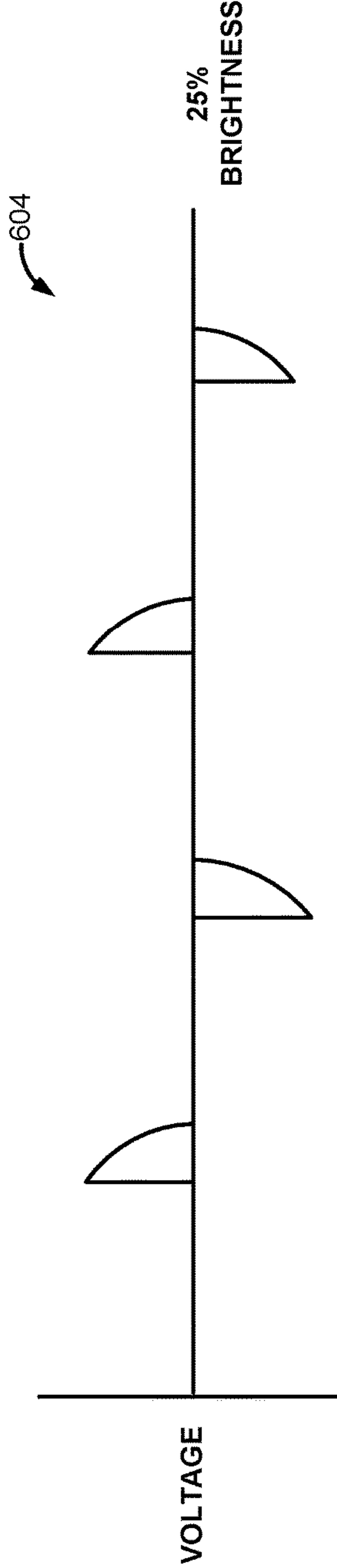


FIG. 6C

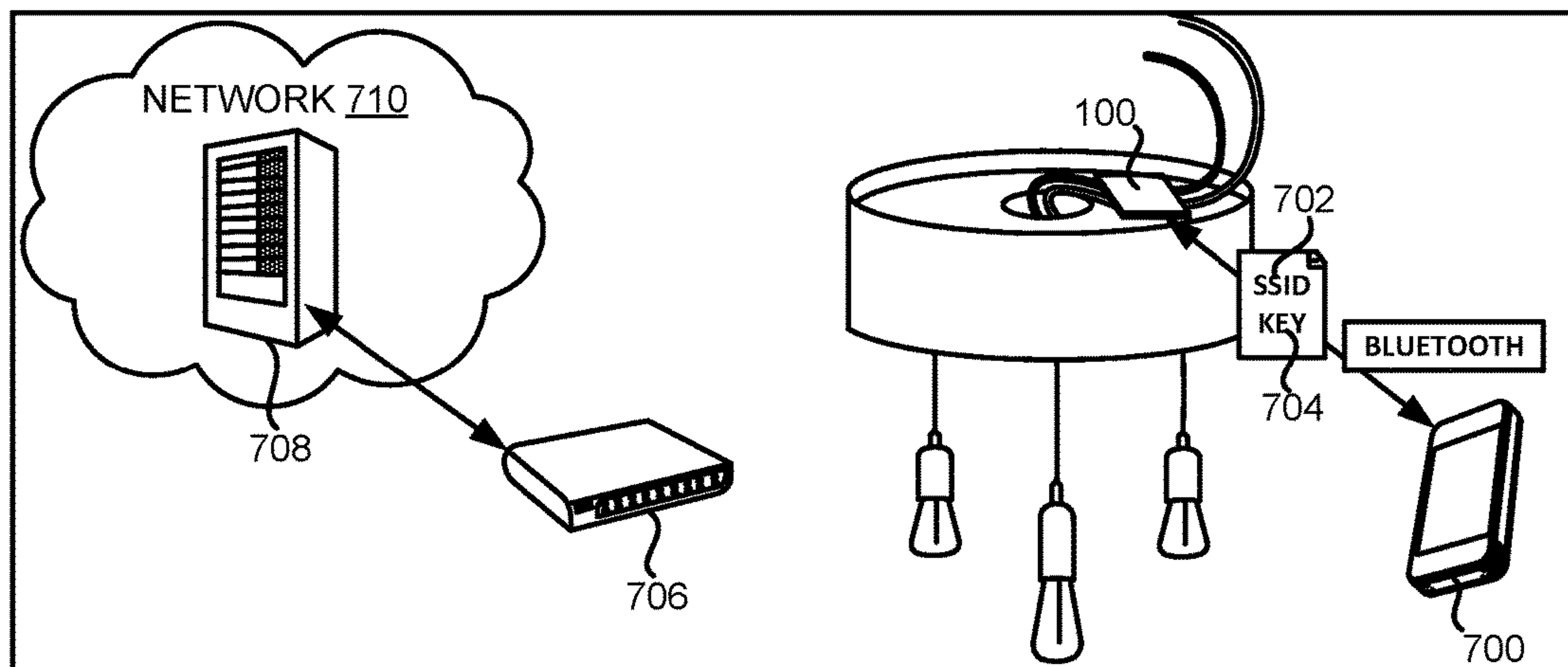


FIG. 7A

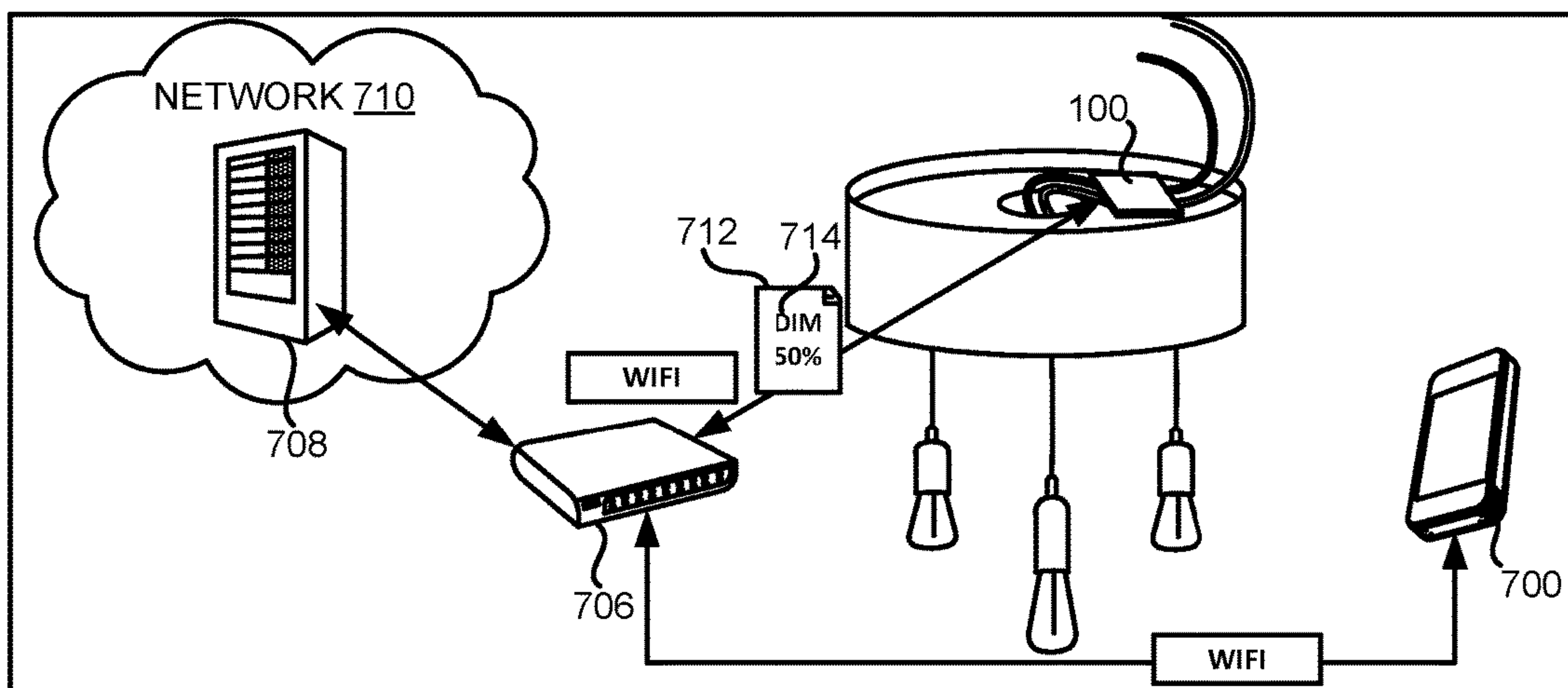


FIG. 7B

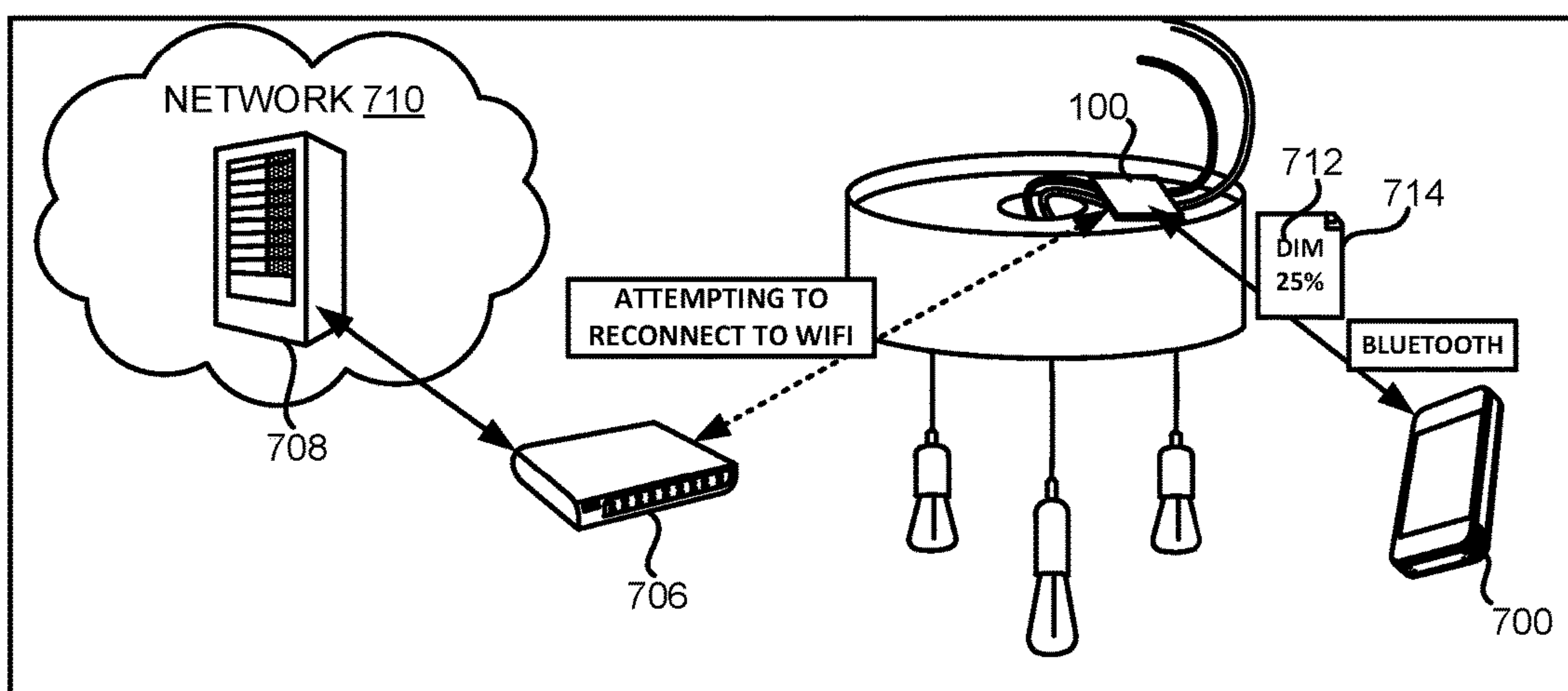


FIG. 7C

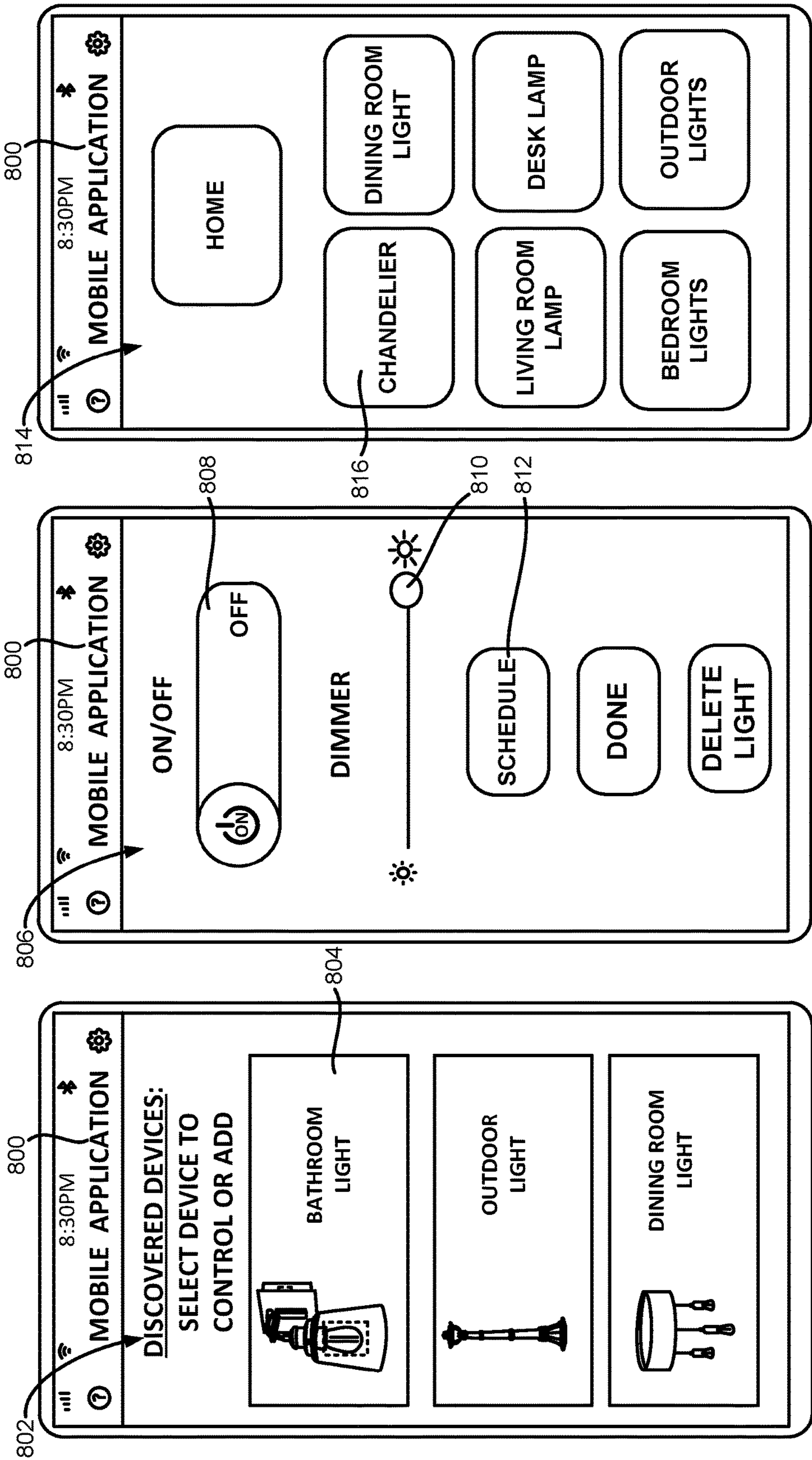


FIG. 8A

FIG. 8B

FIG. 8C

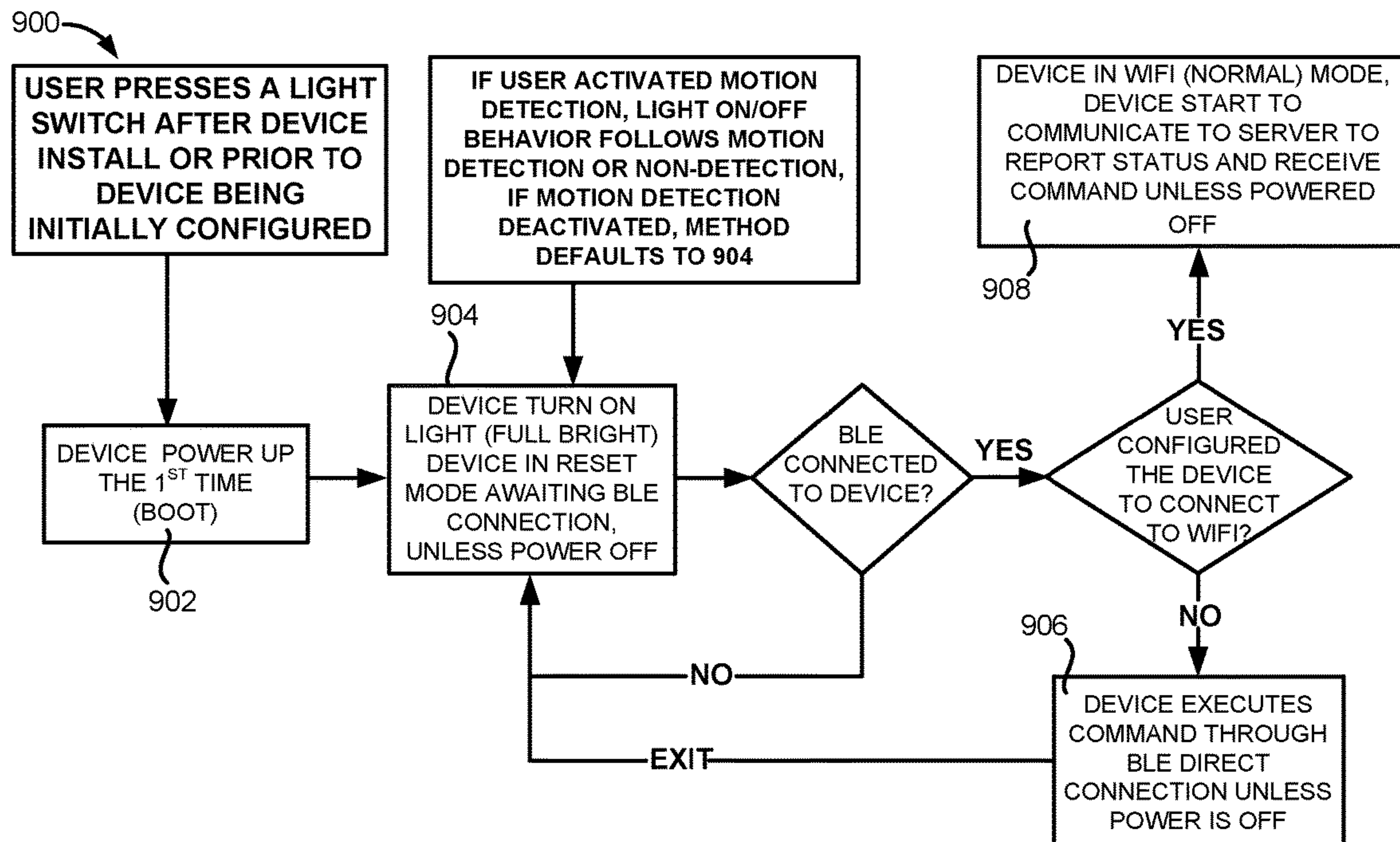


FIG. 9A

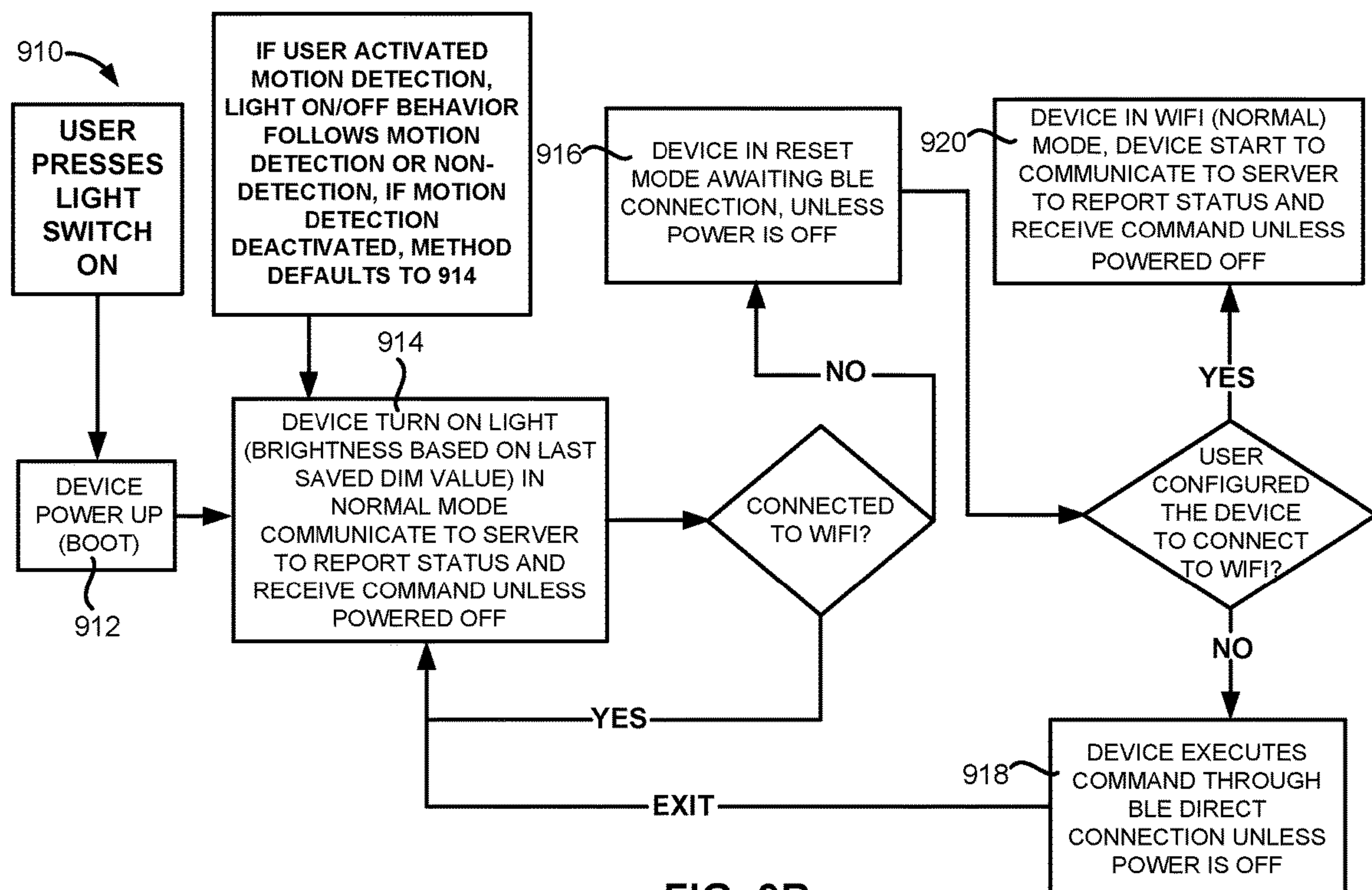


FIG. 9B

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**APPARATUS, SYSTEMS, AND METHODS
FOR REMOTELY DIMMING LIGHTS****CROSS-REFERENCE TO RELATED
APPLICATION**

This application is a continuation-in-part (CIP) of U.S. patent application Ser. No. 16/005,453, filed on Jun. 11, 2018 (now U.S. Pat. No. 10,117,297), the content of which is incorporated herein by reference in its entirety.

TECHNICAL FIELD

This disclosure relates generally to the field of commercial and residential lighting devices and systems, more specifically, to improved apparatus, systems, and methods for remotely dimming alternating current (AC) powered lights.

BACKGROUND

The ability to be able to control one's lights remotely using a smartphone, tablet, or other mobile device is a relatively new phenomenon that will become more commonplace as the smart home or smart office concept is embraced by more appliance and device manufacturers. Such control can include the ability to remotely dim one or more lights within a person's home or office, turn on or off such lights, or even schedule such actions for certain times of the day or night. These devices often fall into three general categories including wirelessly connected lightbulbs, outlets, and light switches. However, all such devices are beset with shortcomings that have heretofore not been addressed by the makers of such devices.

For example, wirelessly connected lightbulbs or smart lightbulbs, such as the Philips Hue™ lightbulbs, often require the user to purchase an expensive bridge or hub device in order to connect such bulbs to the user's wireless local area network (WLAN). Moreover, each smart lightbulb is often three or four times the price of an equivalent lightbulb that does not possess such wireless connectivity. Furthermore, many users have complained that such smart lightbulbs are prone to flickering or producing a buzzing noise compared to regular lightbulbs.

Wirelessly connected light-dimming wall outlets, such as the GE Plug-In Smart Dimmer™, also require the user to purchase an expensive hub device in order to connect such outlets to the user's WLAN. Moreover, light-dimming wall outlets often lose their wireless connection to the hub device, which requires the user to manually reset the wall outlet and provision the outlet once again. In addition, such light-dimming wall outlets can only be used with tabletop or floor lights that have an electrical cord. Furthermore, many users have complained that lights plugged into such light-dimming wall outlets tend to also flicker or produce a buzzing noise compared to lights not plugged into such outlets.

While certain wirelessly connected dimmer switches, such as the WeMo™ Dimmer Light Switch by Belkin International, Inc., do not require an additional hub device to connect to a user's WLAN, such dimmer switches are difficult to install and may require the user to hire a trained professional to replace the user's current light switch with the wirelessly connected dimmer switch. Moreover, such dimmer switches often lose their connection to the user's WLAN, resulting in the user having to physically reset the dimmer switch or re-provision the dimmer switch.

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Therefore, an improved light dimming solution is needed which addresses the challenges faced by current light controlling devices. In addition, such a solution should provide added security benefits and work well with all types of light fixtures and corded lights. Moreover, such a solution should not be overly complex and cost-effective to manufacture.

SUMMARY

Apparatus, systems, and methods for remotely dimming lights are disclosed. In one embodiment, a light-dimming apparatus is disclosed. In some embodiments, the lighting-dimming apparatus can be placed within a lighting enclosure of a light fixture is disclosed. The lighting enclosure can comprise at least one of a canopy of the light fixture, a scone of the light fixture, a flush-mount of the light fixture, a shade holder of the light fixture, and an electrical distribution box of an outdoor light.

The light-dimming apparatus can comprise an AC live input terminal configured to couple to an AC live input wire from a power source, an AC neutral input terminal configured to couple to an AC neutral input wire from the power source, an AC live output terminal configured to couple to an AC live output wire coupled to a lighting load, and an AC neutral output terminal configured to couple to an AC neutral output wire coupled to the lighting load. The lighting load can comprise at least one of an incandescent light bulb, a halogen light bulb, a dimmable light-emitting diode (LED) light bulb, and a dimmable compact fluorescent lamp (CFL) light bulb.

The light-dimming apparatus can also comprise a microcontroller unit comprising a plurality of wireless communication modules, one or more processor cores, and a memory. The plurality of wireless communication modules can comprise a wireless-fidelity (WiFi) module and a Bluetooth™ module.

In addition, the light-dimming apparatus can also comprise an alternating current-to-direct current (AC-to-DC) buck converter coupled to the AC live input terminal, the AC neutral input terminal, and the microcontroller unit. The AC-to-DC buck converter can be configured to deliver power to the microcontroller unit. Moreover, the light-dimming apparatus can also comprise a dimmer module configured to detect a zero-crossing signal and modulate power supplied to the lighting load.

The dimmer module can further comprise a full bridge rectifier electrically coupled to at least the AC live input terminal and the AC neutral input terminal, a first optocoupler electrically coupled to at least the full bridge rectifier and the microcontroller unit, a bidirectional triode thyristor coupled to at least the AC live output terminal, and a second optocoupler coupled to at least the microcontroller unit and the bidirectional triode thyristor.

The one or more processor cores can be programmed to execute instructions stored in the memory of the microcontroller unit to handle a plurality of wireless communication tasks and a plurality of zero-crossing tasks.

The one or more processors core of the microcontroller unit can be programmed to execute instructions stored in the memory of the microcontroller unit to receive a dimming command comprising a dimming value from another device via at least one of the plurality of wireless communication modules to dim a brightness of the lighting load. The one or more processor cores of the microcontroller unit can also be programmed to execute further instructions stored in the memory of the microcontroller unit to receive zero-crossing signals from the dimmer module and transmit a plurality of

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switching signals to the second optocoupler to work with the bidirectional triode thyristor to modulate the power supplied to the lighting load to dim the brightness of the lighting load according to the dimming value.

The one or more processor cores can be programmed to execute further instructions to receive a service set identifier (SSID) of a wireless local area network (WLAN) and a network key associated with the SSID from a client device communicatively coupled to the microcontroller unit over a Bluetooth™ communication protocol via the Bluetooth™ module and store the SSID and the network key in the memory of the microcontroller unit. The one or more processor cores can also be programmed to execute instructions to wirelessly connect to the WLAN using the SSID and the network key. The one or more processor cores can be programmed to execute further instructions to instruct the Bluetooth™ module to cease communication services upon successfully connecting to the WLAN, and receive the dimming command comprising the dimming value from a server over a WiFi communication protocol.

The one or more processor cores can also be programmed to execute instructions stored in the memory of the microcontroller unit to receive the zero-crossing signals from the dimmer module and transmit the plurality of switching signals to the second optocoupler to work with the bidirectional triode thyristor to modulate the power supplied to the lighting load to dim the brightness of the lighting load according to the dimming value received from the server.

For example, the one or more processor cores can be programmed to execute further instructions stored in the memory of the microcontroller unit to instruct the Bluetooth™ module to cease communication services undertaken by the Bluetooth™ module.

The one or more processor cores can be programmed to execute additional instructions stored in the memory of the microcontroller unit to detect that the WiFi module is disconnected from the WLAN, instruct the Bluetooth™ module to resume communication services upon detecting that the WiFi module is disconnected from the WLAN, broadcast a device name of the light-dimming apparatus to client devices within range of the Bluetooth™ module while simultaneously attempting to wirelessly reconnect to the WLAN using the SSID and the network key stored in the memory of the microcontroller unit, wirelessly reconnect to the WLAN using the SSID and the network key stored in the memory of the microcontroller unit, and instruct the Bluetooth™ module to once again cease communication services upon successfully connecting to the WLAN.

The one or more processor cores can also be programmed to execute further instructions stored in the memory of the microcontroller unit to detect that the WiFi module is disconnected from the WLAN, instruct the Bluetooth™ module to resume communication services upon detecting that the WiFi module is disconnected from the WLAN, and receive another dimming command comprising another dimming value from the same client device or another client device wirelessly connected to the light-dimming apparatus via the Bluetooth™ module. In this embodiment, the one or more processor cores can be programmed to execute additional instructions stored in the memory of the microcontroller unit to receive other zero-crossing signals from the dimmer module and transmit additional switching signals to the second optocoupler to work with the bidirectional triode thyristor to modulate the power supplied to the lighting load to dim the brightness of the lighting load according to the dimming value received from the same client device or another client device.

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The light-dimming apparatus can further comprise a single or a plurality of motion sensing modules. Each of the one or more motion sensing modules can comprise a single or a plurality of motion sensors. The one or more motion sensing modules can be coupled to the microcontroller unit. The one or more motion sensing modules can be configured to detect a physical motion or movement using the one or more motion sensors and transmit at least one of a digital signal and an analog signal to the microcontroller unit to inform the microcontroller unit of the detected motion or movement. The one or more processor cores of the microcontroller unit can be further programmed to execute instructions stored in the memory to transmit one or more switching signals to the dimmer module to supply power to the lighting load in response to the at least one of the digital signal and the analog signal received from the one or more motion sensing modules.

A lighting system is also disclosed comprising a light socket configured to couple to a lighting load, a lighting enclosure coupled to the light socket. The lighting enclosure can be configured to house the aforementioned light-dimming apparatus.

A method of dimming a light is also disclosed. The method can comprise using one or more processor cores of the microcontroller unit to execute instructions stored in a memory of a microcontroller unit of the aforementioned light-dimming apparatus to receive a dimming command comprising a dimming value via at least one of a wireless-fidelity (WiFi) module and a Bluetooth™ module of the microcontroller unit from another device to dim a brightness of a lighting load. The method can further comprise using the one or more processor cores of the microcontroller unit to execute further instructions stored in the memory of the microcontroller unit to receive zero-crossing signals from a dimmer module and transmit a plurality of switching signals to the second optocoupler to work with the bidirectional triode thyristor to modulate the power supplied to the lighting load to dim the brightness of the lighting load according to the dimming value.

The method can further comprise using the one or more processor cores to execute instructions stored in the memory of the microcontroller unit to receive a SSID of a WLAN and a network key associated with the SSID from a client device communicatively coupled to the microcontroller unit over a Bluetooth™ communication protocol via the Bluetooth™ module and store the SSID and the network key in the memory of the microcontroller unit. The method can also comprise using the one or more processor cores to execute instructions stored in the memory of the microcontroller unit to wirelessly connect to the WLAN using the SSID and the network key and instruct the Bluetooth™ module to cease communication services upon successfully connecting to the WLAN. The one or more processor cores can turn off the Bluetooth™ module by ceasing certain services undertaken by the Bluetooth™ module.

The method can further comprise receiving the dimming command comprising the dimming value from a server over a WiFi communication protocol and using the one or more processor cores to execute instructions stored in the memory of the microcontroller unit to receive zero-crossing signals from the dimmer module and transmit the plurality of switching signals to the second optocoupler to work with the bidirectional triode thyristor to modulate the power supplied to the lighting load to dim the brightness of the lighting load according to the dimming value received from the server.

The method can further comprise using the one or more processor cores to execute instructions stored in the memory

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of the microcontroller unit to detect that the WiFi module is disconnected from the WLAN, instruct the Bluetooth™ module to resume communication services upon detecting that the WiFi module is disconnected from the WLAN, broadcast a device name of the light-dimming apparatus to client devices within range of the Bluetooth™ module while simultaneously attempting to wirelessly reconnect to the WLAN using the SSID and the network key stored in the memory of the microcontroller unit, wirelessly reconnect to the WLAN using the SSID and the network key stored in the memory of the microcontroller unit, and instruct the Bluetooth™ module to once again cease communication services upon successfully connecting to the WLAN.

The method can further comprise using the one or more processor cores to execute instructions stored in the memory of the microcontroller unit to detect that the WiFi module is disconnected from the WLAN, instruct the Bluetooth™ module to resume communication services upon detecting that the WiFi module is disconnected from the WLAN, and receive another dimming command comprising another dimming value from the same client device or another client device wirelessly connected to the light-dimming apparatus via the Bluetooth™ module. The method can also comprise using the one or more processor cores to execute instructions stored in the memory of the microcontroller unit to receive zero-crossing signals from the dimmer module and transmit switching signals to the second optocoupler to work with the bidirectional triode thyristor to modulate the power supplied to the lighting load to dim the brightness of the lighting load according to the dimming value received from the same client device or another client device.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1A illustrates an embodiment of a light-dimming apparatus placed within a canopy of a ceiling mounted light fixture.

FIG. 1B illustrates the light-dimming apparatus placed within a shade holder of a torchiere floor light.

FIG. 2 illustrates the light-dimming apparatus placed within a scone of a wall-mounted light fixture.

FIG. 3 illustrates the light-dimming apparatus placed within an electrical distribution box of an outdoor lighting system.

FIG. 4 is a schematic showing certain electronic components of the light-dimming apparatus coupled to a printed circuit board (PCB).

FIG. 5 illustrates an embodiment of a microcontroller unit of the light-dimming apparatus.

FIGS. 6A to 6C illustrate example waveforms of alternating current being phase controlled by the light-dimming apparatus.

FIGS. 7A to 7C illustrate the light-dimming apparatus in operation.

FIGS. 8A to 8C illustrate example graphical user interfaces (GUIs) of a mobile application controlling the light-dimming apparatus.

FIG. 9A is a flowchart of an example operating procedure undertaken by the light-dimming apparatus after a user turns on a light fixture comprising the light-dimming apparatus for the first time.

FIG. 9B is a flowchart of another example operating procedure undertaken by the light-dimming apparatus after a user turns on the light-fixture comprising the light-dimming apparatus after the lighting-dimming apparatus has been configured.

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DETAILED DESCRIPTION OF THE INVENTION

FIG. 1A illustrates an embodiment of a light-dimming apparatus **100** placed within a lighting enclosure **102** of a lighting system **104**. As shown in FIG. 1A, the lighting enclosure **102** can be a canopy of a ceiling mounted light fixture. The ceiling mounted light fixture can be considered an embodiment of the lighting system **104**. The lighting system **104** can also comprise one or more light sockets **106** configured to couple to or receive a lighting load **108**. In some embodiments, the lighting load **108** can be an alternating current-powered (AC-powered) lighting load such as an incandescent lamp **200** or lightbulb (see FIG. 2), a halogen lamp **206** or lightbulb (see FIG. 2), a dimmable LED lamp **204** or lightbulb comprising an AC-DC LED driver (see FIG. 2), or a dimmable compact fluorescent lamp (CFL) **202** or lightbulb comprising a dimmable CFL ballast (see FIG. 2). In other embodiments, the lighting load **108** can be a driverless AC-LED lamp or lightbulb. For purposes of this disclosure, the terms “lamp” and “lightbulb” are used interchangeably to refer to an electric-powered element comprising a transparent or translucent housing, a base or connector portion, and any embedded electronic components within the base or connector portion.

FIG. 1A illustrates that the light-dimming apparatus **100** can be placed within a recess **110** or cavity of the lighting enclosure **102**. The light-dimming apparatus **100** can be affixed or otherwise coupled to one or more surfaces within the lighting enclosure **102** by fasteners, adhesives, hook-and-loop fasteners (e.g., Velcro®), soldering, or a combination thereof. For example, the light-dimming apparatus **100** can be placed within the recess **110** of a canopy or flush-mount of a ceiling-mounted light fixture. The light-dimming apparatus **100** can comprise an apparatus housing **111**. The apparatus housing **111** can be shaped to conform to the recess **110** of the lighting enclosure **102**. For example, the apparatus housing **111** can be shaped substantially as a cuboid, an ovoid, a conic or frustoconic, a cylinder, or a combination thereof. In one embodiment, the apparatus housing **111** can be a cuboid having a length dimension of approximately 6.0 cm, a width dimension of approximately 5.0 cm, and a height dimension of approximately 1.5 cm. The apparatus housing **111** can be small enough to fit within the lighting enclosure **102** of most standard-sized lighting fixtures.

The light-dimming apparatus **100** can be coupled in series electrical connection with input wires from an AC power supply, such as the mains power of a residential or commercial building (e.g., 120V/240V and 60 Hz, 230V/240V and 50 Hz, 220V and 50 Hz, 100V and 50 Hz/60 Hz, 120V and 60 Hz, etc.) and the output wires to the lighting load **108**. In the example embodiment shown in FIG. 1A, the light-dimming apparatus **100** can be coupled to an AC live input wire **112** and an AC neutral input wire **114** of the AC power supply and an AC live output wire **116** and an AC neutral output wire **118** coupled to the lighting load **108**.

The AC live input wire **112** and the AC neutral input wire **114** can also be coupled to a wall-mounted lighting control **120**. In some embodiments, the wall-mounted lighting control **120** can comprise a light switch such as a single-pole switch, a double-pole switch, a three-way switch, or a four-way switch. In these embodiments, the wall-mounted lighting control **120** can be implemented as a toggle switch, a rocker switch, a push-buttons switch, or a specialty switch. In other embodiments, the wall-mounted lighting control

120 can comprise a single-pole dimmer, a three-way dimmer, or a multi-location dimmer.

One advantage of the lighting system 104 and the light-dimming apparatus 100 disclosed herein is the compatibility of the system 104 and apparatus 100 with different types of wall-mounted lighting controls. For example, a user can replace an existing light-fixture with the lighting system 104 disclosed herein without having to replace the wall-mounted lighting control 120 currently in place. Moreover, the user can dim one or more lighting loads 108 coupled to the newly installed lighting system 104 even when the existing wall-mounted lighting control 120 is not a dimmer-type control.

FIG. 1B illustrates the light-dimming apparatus 100 placed within a shade holder of a standalone light (e.g., a torchiere floor light) having an AC power plug 122. The standalone light having the AC power plug 122 can be considered an embodiment of the lighting system 104 and the shade holder can be considered an embodiment of the lighting enclosure 102. Although FIG. 1B shows the shade holder as part of a standalone light, it is contemplated by this disclosure and it should be understood by one of ordinary skill in the art that the shade holder can also be part of a wall-mounted or ceiling-mounted light fixture.

One advantage of the lighting system 104 and the light-dimming apparatus 100 disclosed herein is the compatibility of the system 104 and apparatus 100 with standalone lights and fixed lighting structures. For example, a lighting manufacturer can install similar instances of the light-dimming apparatus 100 within the lighting enclosure 102 (e.g., a canopy or flush-mount) of a wall-mounted or ceiling-mounted light fixture and the lighting enclosure 102 (e.g., a shade holder) of a standalone light powered via an AC power plug 122. This makes the light-dimming apparatus 100 a cost-effective solution for lighting manufacturers intending to convert various types of non-connected lights or light fixtures into wirelessly-connected lights or light fixtures.

FIG. 2 illustrates the light-dimming apparatus 100 placed within a scone of a wall-mounted light fixture. The wall-mounted light fixture can be considered an embodiment of the lighting system 104 and the scone can be considered an embodiment of the lighting enclosure 102. As previously discussed, the light-dimming apparatus 100 can modulate power supplied to a lighting load 108. The lighting load 108 can comprise an incandescent lamp 200, a dimmable CFL 202 comprising a CFL ballast, a dimmable LED lamp 204 comprising an AC-DC LED driver, or a halogen lamp 206 (see FIG. 2).

One advantage of the lighting system 104 and the light-dimming apparatus 100 disclosed herein is the compatibility of the system 104 and apparatus 100 with various kinds of lightbulbs or lamps. Moreover, the system 104 and apparatus 100 disclosed herein does not require the user to purchase expensive “smart” lightbulbs and hubs in order to remotely dim such lightbulbs or lamps.

FIG. 3 illustrates the light-dimming apparatus 100 placed within an electrical distribution box 300 coupled to one or more outdoor lights 302. For example, the light-dimming apparatus 100 can be coupled to an AC live input wire 112 and an AC neutral input wire 114 (not shown in FIG. 3) of the AC power supply and an AC live output wire 116 and an AC neutral output wire 118 (not shown in FIG. 3) coupled to the one or more outdoor lights 302. As shown in FIG. 3, the light-dimming apparatus 100 can be used to remotely control one or more outdoor lights 302.

FIG. 4 is a schematic showing certain electronic components of the light-dimming apparatus 100 coupled to a PCB 400 within the apparatus housing 111. As depicted in FIG. 4,

the light-dimming apparatus 100 can comprise a microcontroller unit 402, an AC dimmer module 404, an alternating current-to-direct current (AC-to-DC) buck converter 406, one or more motion sensing modules 407, an AC live input terminal 408, an AC neutral input terminal 410, an AC live output terminal 412, and an AC neutral output terminal 414 coupled to the PCB 400.

The AC live input terminal 408 can be configured to couple to an AC live input wire 112 (see, for example, FIGS. 1A and 1B, also referred to as a “hot wire”) from a power source such as an AC mains power. The AC neutral input terminal 410 can be configured to couple to an AC neutral input wire 114 (see, for example, FIGS. 1A and 1B, also referred to as a “neutral wire”). The AC neutral input wire can be coupled to ground at a breaker box of a residential or commercial building. In some embodiments, the AC live input wire 112 and the AC neutral input wire 114 can be wires extending through the walls or ceiling of a residential or commercial building (see FIG. 1A). In other embodiments, the AC live input wire 112 and the AC neutral input wire 114 can be the hot and neutral wires, respectively, of an AC power cord.

The AC live output terminal 412 can be configured to couple to an AC live output wire 116 coupled to the lighting load 108 (see, for example, FIGS. 1A and 1B). The AC neutral output terminal 414 can be configured to couple to an AC neutral output wire 118 coupled to the lighting load 108 (see, for example, FIGS. 1A and 1B).

The microcontroller unit 402 can comprise a plurality of wireless communication modules including a WiFi module 506 (see FIG. 5) and a Bluetooth™ module 508 (see FIG. 5), multiple processor cores including at least a first CPU or processor core 500 (see FIG. 5) and a second CPU or processor core 502 (see FIG. 5), and a plurality of memory units 504 (see FIG. 5). In some embodiments, the microcontroller unit 402 can comprise only one CPU or processor core (such as only the first processor core 500).

As will be discussed in more detail in the following sections, the first processor core 500 can be programmed to execute instructions stored in the one or more memory units 504 to handle communication via the WiFi module 506 and the Bluetooth™ module 508. For example, the first processor core 500 can be programmed to execute instructions to receive a dimming command 712 comprising a dimming value 714 (see FIGS. 7B and 7C) from another device via one of the wireless communication modules. The second processor core 502 can be programmed to execute instructions stored in the one or more memory units 504 to handle zero-crossing interrupts and control the AC dimmer module 404 to modulate power supplied to the lighting load 108 to dim the brightness of the lighting load 108 according to the dimming value 714. The two processor cores can operate independently such that communication tasks are not interrupted by dimming tasks, and vice versa.

In some embodiments, the same processor core (e.g., the first processor core 500) can be further programmed to execute instructions stored in the one or more memory units 504 to handle zero-crossing interrupts and control the AC dimmer module 404 to modulate power supplied to the lighting load 108 to dim the brightness of the lighting load 108 according to the dimming value 714.

In one embodiment, the microcontroller unit 402 can be an ESP32-WROOM-32 microcontroller unit developed by Espressif Systems (Shanghai) Pte., Ltd. In this embodiment, the first processor core 500 and the second processor core

502 can each be a 32-bit microprocessor such as the Xtensa® LX6 microprocessor from Cadence Design Systems, Inc.

The microcontroller unit 402 can be powered by the AC-to-DC buck converter 406. The AC-to-DC buck converter 406 can be coupled to the AC live input terminal 408 and the AC live input terminal 408. The AC-to-DC buck converter 406 can be configured to convert AC mains power to a 3.3V DC voltage capable of powering the microcontroller unit 402, the one or more motion sensing modules 407, and other electronic components. The AC-to-DC buck converter 406 can have a rated input voltage of between 100V and 240V. The AC-to-DC buck converter 406 can have a load rated output voltage of $+3.3V \pm 0.1V$. In one embodiment, the AC-to-DC buck converter 406 can be an HLK-PM03 converter developed by Shenzhen Hi-Link Electronic Co., Ltd.

The microcontroller unit 402 can be coupled to and control the AC dimmer module 404. The AC dimmer module 404 can comprise a full bridge rectifier 416, a first optocoupler 418, a second optocoupler 420, and a bidirectional triode thyristor 422 (or TRIAC).

The full bridge rectifier 416 (also referred to as a full-wave bridge rectifier) can rectify the AC mains power received through the input wires. The full bridge rectifier 416 can be electrically coupled or connected to the AC live input terminal 408 and the AC neutral input terminal 410. The full bridge rectifier 416 can serve as part of a zero-crossing detector (along with the first optocoupler 418) of the AC dimmer module 404. The full bridge rectifier 416 can output a rectified waveform to the first optocoupler 418. In one embodiment, the full bridge rectifier 416 can be an MB4S Bridge Rectifier developed by Vishay Intertechnology, Inc.

The first optocoupler 418 (also referred to as an optoisolator) can be electrically coupled or connected to at least the full bridge rectifier 416 and the microcontroller unit 402. In some embodiments, the first optocoupler 418 can comprise a gallium arsenide (GaAs) infrared emitting diode and a silicon photo-transistor. The diode can emit light until the AC voltage nears the zero-crossing line, once this occurs, the silicon photo-transistor can output a zero-crossing signal to the microcontroller unit 402. In one embodiment, the first optocoupler 418 can be a 4N25SR2M Phototransistor Optocoupler developed by Semiconductor Component Industries, LLC (d/b/a ON Semiconductor).

The AC dimmer module 404 can also comprise the second optocoupler 420 coupled to the microcontroller unit 402 and the bidirectional triode thyristor 422 (or TRIAC). The bidirectional triode thyristor 422 can be coupled to the AC live output terminal 412 and the AC neutral output terminal 414. The second optocoupler 420 can be used as an optically isolated TRIAC drive device. In some embodiments, the second optocoupler 420 can comprise a GaAs infrared emitting diode and a silicon bilateral switch.

In one embodiment, the second optocoupler 420 can be a MOC30121M TRIAC Driver Output Optocoupler developed by Semiconductor Component Industries, LLC (d/b/a ON Semiconductor). In this and other embodiments, the bidirectional triode thyristor 422 can be a BTA16-600BRG TRIAC device developed by STMicroelectronics International N.V.

The microcontroller unit 402 can be programmed to transmit a plurality of switching signals to the second optocoupler 420 to work with the bidirectional triode thyristor 422 to modulate the power supplied to the lighting load 108. For example, the second optocoupler 420 and the

bidirectional triode thyristor 422 can work to cut power delivered to the lighting load 108 when the AC signal reaches the zero-crossing line. In addition, the microcontroller unit 402 can be programmed to send switching signals to the second optocoupler 420 via the bidirectional triode thyristor 422 to deliver power to the lighting load 108. In this manner, lower average power can be delivered to the lighting load 108 to dim the lighting load 108.

FIG. 4 illustrates that the one or more motion sensing modules 407 can be coupled to the same PCB 400 as the microcontroller unit 402. Each of the one or more motion sensing modules 407 can comprise one or more motion sensors 409. In some embodiments, the motion sensors 409 can comprise an infrared motion sensor, a passive infrared (PIR) motion sensor, an ultrasonic motion sensor, a microwave motion sensor, a tomographic motion sensor, or a combination thereof. The one or more motion sensing modules 407 can be coupled to the microcontroller unit 402 and the one or more motion sensing modules 407 can transmit one or more digital signals, analog signals, or a combination thereof to the microcontroller unit 402.

The one or more motion sensing modules 407 can be configured to detect a physical motion or movement using the one or more motion sensors 409 and transmit at least one of a digital signal and an analog signal (i.e., one or more digital signals, one or more analog signals, or a combination thereof) to the microcontroller unit 402 to inform the microcontroller unit 402 of the detected motion or movement (e.g., a user of the light-dimming apparatus 100 entering a room). The one or more processor cores (e.g., the first processor core 500, the second processor core 502, or a combination thereof) of the microcontroller unit 402 can further be programmed to execute instructions stored in the memory units 504 to transmit one or more switching signals to the dimmer module 404 to supply power to the lighting load 108 in response to the at least one of the digital signal and the analog signal received from the one or more motion sensing modules 407.

The one or more motion sensing modules 407 can also be configured to transmit at least one or more analog signals, digital signals, or a combination thereof to the microcontroller unit 402 to inform the microcontroller unit 402 that no motion has been detected by the one or more motion sensors 409 for a predetermined period of time. In this case, the microcontroller unit 402 can further be programmed to execute instructions stored in the memory units 504 to cease supplying power to the lighting load 108 (i.e., turn off the light).

One or more processor cores (e.g., the first processor core 500) of the microcontroller unit 402 can also be programmed to execute instructions stored in the one or more memory units 504 to transmit a motion status change alert to the server 708 via the WiFi module 506. The server 708, in response to receiving the motion status alert, can transmit an email alert or a text message alert or push notification to a client device 700 informing a user that a motion was detected in a vicinity of the one or more motion sensors 409.

FIG. 5 illustrates an embodiment of the microcontroller unit 402 of the light-dimming apparatus 100. The microcontroller unit 402 can comprise a first CPU or processor core 500, a second CPU or processor core 502, a plurality of memory units 504, a WiFi module 506, and a Bluetooth™ module 508.

In one embodiment, the microcontroller unit 402 can be an ESP32-WROOM-32 microcontroller unit developed by Espressif Systems (Shanghai) Pte., Ltd. In this embodiment, the multiple processor cores including at least the first

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processor core **500** and the second processor core **502** can each be a 32-bit microprocessor such as the Xtensa® LX6 microprocessor from Cadence Design Systems, Inc. In some embodiments, the first processor core **500** and the second processor core **502** can each operate at a clock frequency of between about 160 MHz and 240 MHz. The two processor cores can be configured to operate independently such that tasks pinned to one processor core are not interrupted by tasks pinned to another processor core.

The memory units **504** can comprise read-only memory (ROM) (e.g., up to 448 kB of ROM for booting and core functions), on-chip static random-access memory (SRAM) (e.g., up to 520 kB of SRAM for data and instructions), flash memory (e.g., up to 16 MB of flash memory), or a combination thereof. Firmware instructions can be stored on one or more of the memory units **504** to operate the microcontroller unit **402** and the other electronic components of the light-dimming apparatus **100**. In one embodiment, the firmware instructions can be written in the C programming language. In another embodiment, the firmware instructions can be written in the C++ programming language.

The WiFi module **506** can support a number of WiFi communication protocols including the IEEE 802.11b protocol, the IEEE 802.11g protocol, the IEEE 802.11n protocol, or a combination thereof. The WiFi module **506** can also support communications over the 2.4 GHz ISM band. The WiFi module **506** can allow the light-dimming apparatus **100** to wirelessly connect with a wireless networking device **706** (see FIGS. 7A to 7C) to communicate with one or more servers or client devices over a wide area network (WAN), such as the Internet.

The Bluetooth™ module **508** can support communications using a Bluetooth™ (IEEE 802.15.1) Basic Rate/Enhanced Data Rate (BR/EDR) protocol, a Bluetooth Low Energy (BLE) or Bluetooth Smart™ protocol, or a combination hereof. The Bluetooth™ module **508** can also support various features described in version 4.2 of the Core Bluetooth™ Specification. The Bluetooth™ module **508** can allow the light-dimming apparatus **100** to wirelessly communicate directly with a client device **700** (see FIGS. 7A to 7C) within range of the light-dimming apparatus **100** (for example, to provision the light-dimming apparatus **100** with credentials to connect to a wireless router). Moreover, the Bluetooth™ module **508** can also allow the client device **700** to transmit dimming commands directly to the light-dimming apparatus **100**.

As previously discussed, the first processor core **500** can be programmed to exclusively handle wireless communication tasks while the second processor core **502** can be programmed to exclusively handle AC phase control or zero-crossing interrupt tasks. In other embodiments, the same one processor core (such as the first processor core **500**) can also be programmed to handle wireless communication tasks and AC phase control or zero-crossing interrupt tasks.

The first processor core **500** can be programmed to execute instructions stored in one or more memory units **504** of the microcontroller unit **402** to pin a plurality of wireless communication tasks (e.g., Bluetooth™ communications, WiFi communications, Hypertext Transfer Protocol (HTTP) tasks, or a combination thereof) to the first processor core **500** such that the wireless communication tasks are handled exclusively by the first processor core **500**.

For example, the first processor core **500** can execute the following code in order to pin certain wireless communication tasks to the first processor core **500** (referred to below as core 0):

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```
BLE: xTaskCreatePinnedToCore(btc_task, "Btc_task",
    BTC_TASK_STACK_SIZE, NULL, BTC_TASK_
    PRIO, &xBtcTaskHandle, 0);
http: xTaskCreatePinnedToCore(&http_get_task, "http_
    get_task", 4096, NULL, 5, NULL, 0);
System thread: result=xTaskCreatePinnedToCore(thread,
    name, stacksize, arg, prio, &CreatedTask, 0);
System timer: xReturn=xTaskCreatePinnedToCore(prv-
    TimerTask, "Tmr Svc", (uint16_t) configTIMER_
    TASK_STACK_DEPTH, NULL, ((UBaseType_t) con-
    figTIMER_TASK_PRIORITY)|portPRIVILEGE_BIT,
    &xTimerTaskHandle, 0)
```

As a more specific example, the first processor core **500** can be programmed to execute instructions stored in the one or more memory units **504** to receive or request a dimming command **712** or instruction comprising a dimming value **714** (see FIGS. 7B and 7C) from a server **708** via the WiFi module **506** to dim a brightness of a lighting load **108**. In addition, the first processor core **500** can be programmed to execute instructions stored in the one or more memory units **504** to receive a dimming command **712** or instruction comprising a dimming value **714** from a client device **700** via the Bluetooth™ module **508** to dim a brightness of a lighting load **108**.

The second processor core **502** can be programmed to execute instructions stored in the one or more memory units **504** of the microcontroller unit **402** to pin a plurality of AC phase control or zero-crossing tasks to the second processor core **502** such that zero-crossing interrupts are handled exclusively by the second processor core **502**.

For example, the second processor core **502** can execute the following code in order to pin certain AC phase control or zero-crossing tasks to the second processor core **502** (referred to below as core 1):

```
xTaskCreatePinnedToCore(&zero_task, "zero_task", 40-
    96, NULL, 15, NULL, 1)
```

As a more specific example, the second processor core **502** can be programmed to execute instructions stored in the one or more memory units **504** to receive zero-crossing signals from the dimmer module **404** (e.g., from the first optocoupler **418**) and transmit a plurality of switching signals to the second optocoupler **420** to work with the bidirectional triode thyristor **422** to modulate the power supplied to the lighting load **108** to dim the brightness of the lighting load **108** according to the dimming value **714**.

One advantage of pinning separate tasks to the two processor cores is that the two processor cores can operate at full capacity without being interrupted at random. Another advantage of the dual-core architecture disclosed herein is that the PCB **400** of the light-dimming apparatus **100** is less complex and the light-dimming apparatus **100** as a whole is more cost-effective to manufacture.

In addition, an unexpected discovery made by the applicants is that a lighting load **108** dimmed by the dual-core microcontroller unit **402** disclosed herein (i.e., pinning wireless communication tasks to one CPU core and pinning zero-crossing tasks to another CPU core) exhibited less noticeable flickering than similar lighting loads dimmed by lighting systems or dimmers comprising microcontroller units having a single CPU core. Another unexpected discovery made by the applicants is that the light-dimming apparatus **100** timed out less often from a wireless connectivity standpoint than other wirelessly connected dimmers. This allows the light-dimming apparatus **100** and the lighting system **104** comprising the light-dimming apparatus **100** to operate for longer stretches without having to reset the light-dimming apparatus **100**.

In an alternative embodiment, the first processor core **500** can also be programmed to execute instructions stored in the one or more memory units **504** to receive zero-crossing signals from the dimmer module **404** (e.g., from the first optocoupler **418**) and transmit a plurality of switching signals to the second optocoupler **420** to work with the bidirectional triode thyristor **422** to modulate the power supplied to the lighting load **108** to dim the brightness of the lighting load **108** according to the dimming value **714**.

FIGS. **6A** to **6C** illustrate example waveforms of alternating current being phase controlled by the light-dimming apparatus **100**. For example, phase diagram **600** in FIG. **6A** illustrates an instance where the lighting load **108** is not dimmed (100% brightness) and full sinusoidal AC energy is delivered to the lighting load **108**. Phase diagram **602** in FIG. **6B** illustrates an instance where the lighting load **108** is dimmed to 75% brightness and partial sinusoidal AC energy is delivered to the lighting load **108**. Phase diagram **604** in FIG. **6C** illustrates an instance where the lighting load **108** is dimmed to 25% brightness and even less sinusoidal AC energy is delivered to the lighting load **108**. Since the AC dimmer module **404** of the light-dimming apparatus **100** cuts from the forward phase, the light-dimming apparatus **100** can be considered a forward-phase dimmer.

FIGS. **7A** to **7C** illustrate certain operations undertaken by the light-dimming apparatus **100**. FIG. **7A** illustrates a client device **700** provisioning the light-dimming apparatus **100** with credentials used to access a wireless local area network (WLAN). The light-dimming apparatus **100** can be considered to be in a reset mode prior to connecting to the WLAN. As depicted in FIG. **7A**, a processor core (e.g., the first processor core **500**) of the microcontroller unit **402** of the light-dimming apparatus **100** can be programmed to execute instructions (e.g., firmware instructions) stored in the memory of the microcontroller unit **402** to receive a service set identifier (SSID) **702** of the WLAN and a network key **704** associated with the SSID **702** from the client device **700** over a Bluetooth™ communication protocol (e.g., BLE, Bluetooth™ BR/EDR, etc.). The processor core (e.g., the first processor core **500**) can then be programmed to execute further instructions to store the SSID **702** and the network key **704** in one of the memory units **504** of the microcontroller unit **402**.

The processor core (e.g., the first processor core **500**) can also be programmed to execute instructions to wirelessly connect to the WLAN using the SSID **702** and the network key **704** through a wireless networking device **706**, such as a wireless router or gateway device. Once the light-dimming apparatus **100** has successfully connected to the WLAN, the processor core (e.g., the first processor core **500**) can be further programmed to instruct the Bluetooth™ module **508** to cease communication services or to cease communicating with client devices **700** via a Bluetooth™ communication protocol (e.g., BLE, Bluetooth™ BR/EDR, etc.). In one embodiment, the processor core (e.g., the first processor core **500**) can be programmed to execute instructions stored in one of the memory units **504** of the microcontroller unit **402** to instruct the Bluetooth™ module **508** to cease communication services.

The light-dimming apparatus **100** can temporarily disable or turn off the Bluetooth™ module **508** in order to prevent unauthorized devices from connecting to the light-dimming apparatus **100** via Bluetooth™ once the light-dimming apparatus **100** has been configured. Moreover, once the light-dimming apparatus **100** is able to connect to the WLAN, the light-dimming apparatus **100** can receive commands from a server **708** via a wide area network (WAN) such as network

710 (e.g., the Internet). Once the Bluetooth™ module **508** is turned off or disabled, all control over the light-dimming apparatus **100** is then routed through the server **708**.

The server **708** can be or refer to one or more centralized or stand-alone servers, de-centralized servers, or a combination thereof. For example, the server **708** can be or refer to a cloud computing resource, a virtualized computing resource, a part of a server farm, a server cluster, or a combination thereof. In some embodiments, the server **708** can take the form of a rack-mounted server, a blade server, a mainframe, a dedicated desktop or laptop computer, a portion thereof, one or more processors or processors cores therein, or a combination thereof.

In one embodiment, the client device **700** shown in FIGS. **7A** to **7C** can be or refer to a portable electronic device such as a smartphone, a tablet computer, a laptop computer, a smartwatch, a fitness tracker, or a combination thereof. In other embodiments, the client device **700** can be or refer to a desktop computer, a smart television, a smart home appliance, or a combination thereof.

The client device **700** can communicate with the server **708** by connecting to the WLAN via the wireless networking device **706**. In other embodiments, the client device **700** can communicate with the server **708** through one or more cellular networks using one or more wireless communication protocols or standards such as a 3G wireless communication standard, a 4G wireless communication standard, a 5G wireless communication standard, a long-term evolution (LTE) wireless communication standard, or a combination thereof.

In further embodiments, a voice-enabled assistance device (e.g., Google Home™ Amazon Echo™, etc.) can also be wirelessly connected to the wireless networking device **706**. In these embodiments, a user can voice a command to the voice-enabled assistance device to dim the lights. The voice-enabled assistance device can then transmit a parsed instance of the command to a voice-enabled assistance server via WiFi. The voice-enabled assistance server can then communicate with the server **708** to instruct the server **708** to transmit a dimming command **712** to the light-dimming apparatus **100**.

FIG. **7B** illustrates that the light-dimming apparatus **100** can receive a dimming command **712** comprising a dimming value **714** from the server **708**. The light-dimming apparatus **100** can receive the dimming command **712** via a WiFi communication protocol through the wireless networking device **706**. The dimming command **712** can be instructions transmitted as part of one or more network packets. The dimming value **714** can be a percentage value between 0% and 100%. As will be discussed in more detail in the following sections, the dimming command **712** can be sent from a client device **700** when a user applies a user input to a graphical user interface (GUI) of an application **800** (see FIGS. **8A** to **8C**) running on the client device **700**.

In response to the processor core (e.g., the first processor core **500**) receiving the dimming command **712**, the same processor core or another processor core (e.g., the second processor core **502**) of the microcontroller unit **402** can be programmed to execute instructions stored in one of the memory units **504** of the microcontroller unit **402** to receive a number of zero-crossing signals from the dimmer module **404** and transmit a plurality of switching signals to the second optocoupler **420** in response to the zero-crossing signals. The second optocoupler **420** can then work with the bidirectional triode thyristor **422** (or TRIAC) to modulate the power supplied to the lighting load **108** to dim the brightness of the lighting load **108**.

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FIG. 7C illustrates that a processor core (e.g., the first processor core **500**) can detect that the WiFi module **506** is disconnected from the WLAN (e.g., if the WiFi router is offline). The light-dimming apparatus **100** can enter a reset mode when disconnected from the WLAN. When in the reset mode, the processor core (e.g., the first processor core **500**) can instruct the Bluetooth™ module **508** to resume communication services upon detecting that the WiFi module **506** is disconnected from the WLAN.

The processor core (e.g., the first processor core **500**) can then use the Bluetooth™ module **508** to broadcast a device name or device hardware address to client devices within range of the light-dimming apparatus **100**. The light-dimming apparatus **100** can then connect directly with at least one client device via a Bluetooth™ communication protocol (e.g., BLE, Bluetooth™ BR/EDR, etc.) through the Bluetooth™ module **508**. At this point, the processor core (e.g., the first processor core **500**) can receive dimming commands **712** directly from the client device **700** or another client device via the Bluetooth™ communication protocol (e.g., BLE, Bluetooth™ BR/EDR, etc.) through the Bluetooth™ module **508**. In response to the processor core (e.g., the first processor core **500**) receiving a dimming command **712** from the client device **700** via the Bluetooth™ communication protocol, the same processor core or another processor core (e.g., the second processor core **502**) can be programmed to execute instructions stored in one of the memory units **504** of the microcontroller unit **402** to receive zero-crossing signals from the dimmer module **404** and transmit a plurality of switching signals to the second optocoupler **420** to work with the bidirectional triode thyristor **422** to modulate the power supplied to the lighting load **108** to dim the brightness of the lighting load **108**. The brightness of the lighting load **108** can be dimmed in accordance with the dimming value **714** received as part of the dimming command **712** from the client device **700** or another client device.

FIG. 7C also illustrates that the processor core (e.g., the first processor core **500**) can be programmed to execute instructions to attempt to wirelessly reconnect to the WLAN using the SSID **702** and the network key **704** stored in one of the memory units **504** of the microcontroller unit **402**. The light-dimming apparatus **100** can simultaneously attempt to reconnect to the WLAN while also receiving dimming commands **712** directly from one or more client devices via a Bluetooth™ communication protocol.

Once the light-dimming apparatus **100** has successfully re-connected to the WLAN (e.g., when the wireless router comes back online after going offline for a short period), the light-dimming apparatus **100** can exit the reset mode and enter a normal operating mode. When the light-dimming apparatus **100** is successfully re-connected to the WLAN, the processor core (e.g., the first processor core **500**) can once again instruct the Bluetooth™ module **508** to cease communication services such that dimming commands **712** are once again routed through the server **708**. One advantage of the connection methods described herein is that a user can still operate the lighting system **104** comprising the light-dimming apparatus **100** via the client device **700** using Bluetooth™ when a WiFi connection is down or otherwise unavailable. However, once the light-dimming apparatus **100** is able to re-connect to the WLAN, command of the light-dimming apparatus **100** is routed through the server **708** for added security and the ability to be able to remotely control the light-dimming apparatus **100** from any location with WiFi access.

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FIGS. 8A to 8C illustrate example graphical user interfaces (GUIs) of a mobile application **800** running on a client device **700** used to control the light-dimming apparatus **100**. In some embodiments, the mobile application **800** can be written or coded using the Swift™ programming language, the Objective-C programming language, or a combination thereof when the client device **700** is running an iOS™ operating system. In other embodiments, the mobile application **800** can be written or coded using the Java™ programming language when the client device **700** is running an Android™ operating system. A user can transmit commands to the server **708** to control the light-dimming apparatus **100** by applying a user input to one or more GUI elements rendered through the mobile application **800**. The server **708** (or one or more server processors) can be programmed to execute instructions written in the Java™ programming language, Structured Query Language (SQL) programming language, or a combination thereof to interact and communicate with the client device **700** and the light-dimming apparatus **100**.

FIG. 8A illustrates a device discovery GUI **802** rendered as part of the mobile application **800**. The device discovery GUI **802** can be displayed to a user when at least one lighting system **104** comprising the light-dimming apparatus **100** is in the reset mode and within a short-range communication range (e.g., Bluetooth™ or BLE range) of the client device **700**.

The client device **700** running the mobile application **800** can be programmed to execute application instructions to scan for a light-dimming apparatus **100** that is in the reset mode. A light-dimming apparatus **100** can be in the reset mode when the device has not been configured or provisioned for connection to a WLAN or has recently lost its connection to the WLAN. The device discovery GUI **802** will display a device name or device hardware address of the discovered light-dimming apparatus **100** through a discovered device button **804** or link. The client device **700** can attempt to connect to the discovered light-dimming apparatus **100** using a Bluetooth™ communication protocol (e.g., BLE, Bluetooth™ BR/EDR, etc.) when the user applies a user input to the discovered device button **804** or link. The mobile application **800** can then allow the user to enter provisioning credentials (e.g., the SSID **702** and the network key **704**) for the WLAN through the mobile application **800** to be stored within one of the memory units **504** of the light-dimming apparatus **100**. Moreover, the mobile application **800** can also allow the user to control the light-dimming apparatus **100** directly over the Bluetooth™ communication protocol.

FIG. 8B illustrates a light control GUI **806** rendered as part of the mobile application **800**. The light control GUI **806** can be displayed when a user applies a user input to a specific light identification button **816** or link rendered as part of a lighting summary GUI **814** (see FIG. 8C). As shown in FIG. 8B, the user can turn on or turn off a lighting system **104** comprising the light-dimming apparatus **100** by applying a user input to an ON/OFF button **808** or link rendered as part of the light control GUI **806**. In response to the user applying the user input to the ON/OFF button **808** or link, the client device **700** can transmit an ON/OFF command to the server **708** and the server **708** can, in turn, transmit the ON/OFF command to the light-dimming apparatus **100**. In other embodiments, the client device **700** can transmit the ON/OFF command directly to the light-dimming apparatus **100** when the light-dimming apparatus **100** is in the reset mode and connected to the client device **700** directly over a Bluetooth™ communication protocol.

The user can also generate a dimming command **712** comprising a dimming value **714** by manipulating a dimming control slider **810** rendered as part of the light control GUI **806**. In response to the user applying a user input to manipulate the dimming control slider **810**, the client device **700** can transmit a dimming command **712** comprising a dimming value **714** corresponding to the slider position of the dimming control slider **810** to the server **708**. The server **708** can, in turn, transmit the dimming command **712** to the light-dimming apparatus **100**. In other embodiments, the client device **700** can transmit the dimming command **712** directly to the light-dimming apparatus **100** when the light-dimming apparatus **100** is in the reset mode and connected to the client device **700** directly over a Bluetooth™ communication protocol. In all such embodiments, the dimming command **712** and the dimming value **714** can be stored in at least one of the memory units **504** of the microcontroller unit **402** of the light-dimming apparatus **100** even when the lighting system **104** comprising the light-dimming apparatus **100** is turned off. The light-dimming apparatus **100** can then set the brightness or luminous intensity of the lighting load **108** to its previously saved dimming value **714** when the lighting system **104** is turned on once again.

FIG. **8B** also illustrates that the light control GUI **806** can also comprise a schedule button **812** rendered as part of the light control GUI **806**. In response to the user applying a user input to the schedule button **812**, the client device **700** can transmit scheduling instructions to the server **708**. The scheduling instructions can be stored in one or more server memory units. The server **708** can generate and transmit ON/OFF commands, dimming commands **712**, or a combination thereof to the light-dimming apparatus based on a number of scheduling parameters (e.g., day-of-the week, time-of-the-day, duration, etc.) of the scheduling instructions. By doing so, a user can schedule lighting operations to be undertaken by the light-dimming apparatus **100** in advance.

FIG. **8C** illustrates a light summary GUI **814** comprising a plurality of light identification buttons **816**. Each of the light identification buttons **816** can be associated with a lighting system **104** comprising a light-dimming apparatus **100**. A user can apply a user input to a particular light identification button **816** to bring up the light control GUI **806** for that particular lighting system **104**.

FIG. **9A** illustrates a flowchart depicting one embodiment of an operating procedure **900** undertaken by the light-dimming apparatus **100**. The procedure **900** can be undertaken by the light-dimming apparatus **100** when a user presses a light switch (e.g., a wall-mounted lighting control **120**, such as the one shown in FIG. **1A**) after the lighting system **104** has been installed or prior to the initial configuration of the light-dimming apparatus **100**. Alternatively, if a user has activated motion detection, the light on/off behavior of the light-dimming apparatus **100** can be dictated by the motion or movements detected (or not detected) by the one or more motion sensing modules **407**, if motion detection is deactivated, the procedure **900** defaults to operation **904**. The light-dimming apparatus **100** can power up or boot up for the first time in response to the user pressing a light switch in operation **902**. The light-dimming apparatus **100** can then allow full sinusoidal AC energy to be delivered to the lighting load **108** (i.e., turn on the light to 100% or full brightness) when the light-dimming apparatus **100** is still in a reset mode and awaiting a connection with a client device **700** over BLE or another Bluetooth™ communication protocol in operation **904**.

If the light-dimming apparatus **100** is directly connected to a client device **700** via BLE or another Bluetooth™ communication protocol but not connected to a WLAN, the light-dimming apparatus **100** can execute instructions or commands (dimming commands **712**, ON/OFF commands, or a combination thereof) received directly from the client device **700** in operation **906**. Alternatively, if the light-dimming apparatus **100** receives provisioning credentials (e.g., SSID **702** and network key **704** associated with a WLAN) from the client device **700**, the light-dimming apparatus **100** can enter a normal operating mode and connect with the server **708** over WiFi in operation **908**. While in the normal operating mode, the light-dimming apparatus **100** can receive all instructions and commands from the server **708** and execute instructions to turn off the Bluetooth™ module **508** for security purposes and for operational efficiency.

FIG. **9B** illustrates a flowchart depicting an embodiment of another operating procedure **910** undertaken by the light-dimming apparatus **100** after the user turns on the lighting system **104** and the light-dimming apparatus **100** has been previously configured. Alternatively, if a user has activated motion detection, the light on/off behavior of the light-dimming apparatus **100** can be dictated by the motion or movements detected (or not detected) by the one or more motion sensing modules **407**, if motion detection is deactivated, the procedure **910** defaults to operation **914**. The procedure **910** can comprise the light-dimming apparatus **100** powering up or booting up in response to the user pressing the light switch in operation **912**. The light-dimming apparatus **100** can then turn on the lighting system **104** by setting the brightness of the lighting load **108** to a previously saved dimming value **714** in operation **914**. The light-dimming apparatus **100** can then query if it is connected to a WLAN. If the light-dimming apparatus **100** is connected to the WLAN, the light-dimming apparatus **100** can enter a normal operating mode and connect with the server **708** over WiFi. However, if the light-dimming apparatus **100** is not connected to the WLAN, the light-dimming apparatus **100** can enter a reset mode and await a connection with a client device **700** over BLE or another Bluetooth™ communication protocol in operation **916**. If the light-dimming apparatus **100** is directly connected to a client device **700** over BLE or another Bluetooth™ communication protocol but has not received provisioning credentials (e.g., SSID **702** and network key **704** associated with a WLAN) from the client device **700**, the light-dimming apparatus **100** can execute instructions or commands (dimming commands **712**, ON/OFF commands, or a combination thereof) received directly from the client device **700** in operation **918**. If the light-dimming apparatus **100** has received provisioning credentials (e.g., SSID **702** and network key **704** associated with a WLAN) from the client device **700** and has successfully connected to the WLAN, the light-dimming apparatus **100** can enter a normal operating mode and connect with the server **708** over WiFi in operation **920**. While in a normal operating mode, the light-dimming apparatus **100** can receive all instructions and commands from the server **708** and execute instructions to turn off the Bluetooth™ module **508** for security purposes and for operational efficiency.

A number of embodiments have been described. Nevertheless, it will be understood by one of ordinary skill in the art that various modifications may be made without departing from the spirit and scope of the embodiments. In addition, the flowcharts or logic flows depicted in the figures do not require the particular order shown, or sequential

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order, to achieve desirable results. In addition, other steps or operations may be provided, or steps or operations may be eliminated, from the described flows, and other components may be added to, or removed from, the described systems. Accordingly, other embodiments are within the scope of the following claims.

Each of the individual variations or embodiments described and illustrated herein has discrete components and features which may be readily separated from or combined with the features of any of the other variations or embodiments. Modifications may be made to adapt a particular situation, material, composition of matter, process, process act(s) or step(s) to the objective(s), spirit or scope of the present invention.

Methods recited herein may be carried out in any order of the recited events that is logically possible, as well as the recited order of events. Moreover, additional steps or operations may be provided or steps or operations may be eliminated to achieve the desired result.

Furthermore, where a range of values is provided, every intervening value between the upper and lower limit of that range and any other stated or intervening value in that stated range is encompassed within the invention. Also, any optional feature of the inventive variations described may be set forth and claimed independently, or in combination with any one or more of the features described herein.

All existing subject matter mentioned herein (e.g., publications, patents, and patent applications) is incorporated by reference herein in its entirety except insofar as the subject matter may conflict with that of the present invention (in which case what is present herein shall prevail). The referenced items are provided solely for their disclosure prior to the filing date of the present application. Nothing herein is to be construed as an admission that the present invention is not entitled to antedate such material by virtue of prior invention.

Reference to a singular item, includes the possibility that there are plural of the same items present. More specifically, as used herein and in the appended claims, the singular forms “a,” “an,” “said” and “the” include plural referents unless the context clearly dictates otherwise. It is further noted that the claims may be drafted to exclude any optional element. As such, this statement is intended to serve as antecedent basis for use of such exclusive terminology as “solely,” “only” and the like in connection with the recitation of claim elements, or use of a “negative” limitation. Unless defined otherwise, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this invention belongs.

This disclosure is not intended to be limited to the scope of the particular forms set forth, but is intended to cover alternatives, modifications, and equivalents of the variations or embodiments described herein. Further, the scope of the disclosure fully encompasses other variations or embodiments that may become obvious to those skilled in the art in view of this disclosure.

It will be understood by one of ordinary skill in the art that the various methods disclosed herein may be embodied in a non-transitory readable medium, machine-readable medium, and/or a machine accessible medium comprising instructions compatible, readable, and/or executable by a processor or server processor of a machine, device, or computing device. The structures and modules in the figures may be shown as distinct and communicating with only a few specific structures and not others. The structures may be merged with each other, may perform overlapping functions,

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and may communicate with other structures not shown to be connected in the figures. Accordingly, the specification and/or drawings may be regarded in an illustrative rather than a restrictive sense.

We claim:

1. A light-dimming apparatus, comprising:

an AC live input terminal configured to couple to an AC live input wire from a power source, an AC neutral input terminal configured to couple to an AC neutral input wire, an AC live output terminal configured to couple to an AC live output wire coupled to a lighting load, and an AC neutral output terminal configured to couple to an AC neutral output wire coupled to the lighting load;

a microcontroller unit comprising a plurality of wireless communication modules, one or more processor cores, and a memory;

a dimmer module configured to detect a zero-crossing signal and modulate power supplied to the lighting load, wherein the dimmer module comprises:

a full bridge rectifier electrically coupled to at least the AC live input terminal and the AC neutral input terminal,

a first optocoupler electrically coupled to at least the full bridge rectifier and the microcontroller unit,

a bidirectional triode thyristor coupled to at least the AC live output wire,

a second optocoupler coupled to at least the microcontroller unit and the bidirectional triode thyristor; and

wherein the one or more processor cores of the microcontroller unit is programmed to:

execute instructions stored in the memory of the microcontroller unit to receive a dimming command comprising a dimming value from another device via at least one of the plurality of wireless communication modules to dim a brightness of the lighting load, and execute further instructions stored in the memory of the microcontroller unit to receive zero-crossing signals from the dimmer module and transmit a plurality of switching signals to the second optocoupler to work with the bidirectional triode thyristor to modulate the power supplied to the lighting load to dim the brightness of the lighting load according to the dimming value.

2. The light-dimming apparatus of claim 1, wherein the plurality of wireless communication modules comprise a wireless-fidelity (WiFi) module and a Bluetooth™ module.

3. The light-dimming apparatus of claim 2, wherein the one or more processor cores is further programmed to execute instructions stored in the memory of the microcontroller unit to:

receive a service set identifier (SSID) of a wireless local area network (WLAN) and a network key associated with the SSID from a client device communicatively coupled to the microcontroller unit over a Bluetooth™ communication protocol via the Bluetooth™ module; store the SSID and the network key in the memory of the microcontroller unit;

wirelessly connect to the WLAN using the SSID and the network key;

instruct the Bluetooth™ module to cease communication services upon successfully connecting to the WLAN; receive the dimming command comprising the dimming value from a server over a WiFi communication protocol; and

receive the zero-crossing signals from the dimmer module and transmit the plurality of switching signals to the

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second optocoupler to work with the bidirectional triode thyristor to modulate the power supplied to the lighting load to dim the brightness of the lighting load according to the dimming value received from the server.

4. The light-dimming apparatus of claim 3, wherein the one or more processor cores is further programmed to execute instructions stored in the memory of the microcontroller unit to instruct the Bluetooth™ module to cease communication services undertaken by the Bluetooth™ module.

5. The light-dimming apparatus of claim 3, wherein the one or more processor cores is further programmed to execute instructions stored in the memory of the microcontroller unit to:

detect that the WiFi module is disconnected from the WLAN;

instruct the Bluetooth™ module to resume communication services upon detecting that the WiFi module is disconnected from the WLAN;

broadcast a device name of the light-dimming apparatus to client devices within range of the Bluetooth™ module while simultaneously attempting to wirelessly reconnect to the WLAN using the SSID and the network key stored in the memory of the microcontroller unit;

wirelessly reconnect to the WLAN using the SSID and the network key stored in the memory of the microcontroller unit; and

instruct the Bluetooth™ module to once again cease communication services upon successfully connecting to the WLAN.

6. The light-dimming apparatus of claim 3, wherein the one or more processor cores is further programmed to execute instructions stored in the memory of the microcontroller unit to:

detect that the WiFi module is disconnected from the WLAN;

instruct the Bluetooth™ module to resume communication services upon detecting that the WiFi module is disconnected from the WLAN;

receive another dimming command comprising another dimming value from the same client device or another client device wirelessly connected to the light-dimming apparatus via the Bluetooth™ module; and

receive other zero-crossing signals from the dimmer module and transmit additional switching signals to the second optocoupler to work with the bidirectional triode thyristor to modulate the power supplied to the lighting load to dim the brightness of the lighting load according to the dimming value received from the same client device or another client device.

7. The light-dimming apparatus of claim 1, wherein the light-dimming apparatus is configured to be placed within a lighting enclosure, and wherein the lighting enclosure comprises at least one of a canopy of the AC powered light, a sconce of the AC powered light, a flush-mount of the AC powered light, a shade holder of the AC powered light, and an electrical distribution box of an outdoor AC powered light.

8. The light-dimming apparatus of claim 1, further comprising an alternating current-to-direct current (AC-to-DC) buck converter coupled to the AC live input terminal, the AC neutral input terminal, and the microcontroller unit and configured to deliver power to the microcontroller unit.

9. The light-dimming apparatus of claim 1, further comprising one or more motion sensing modules comprising one

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or more motion sensors, wherein the one or more motion sensing modules are coupled to the microcontroller unit, wherein the one or more motion sensing modules are configured to detect a physical motion or movement using the one or more motion sensors and transmit at least one of a digital signal and an analog signal to the microcontroller unit to inform the microcontroller unit of a detected motion or movement, and wherein the one or more processor cores of the microcontroller unit is further programmed to execute instructions stored in the memory to transmit one or more switching signals to the dimmer module to supply power to the lighting load in response to the at least one of the digital signal and the analog signal received from the one or more motion sensing modules.

10. The light-dimming apparatus of claim 1, wherein the lighting load comprises at least one of an incandescent light bulb, a halogen light bulb, a dimmable light-emitting diode (LED) light bulb, and a dimmable compact fluorescent lamp (CFL) light bulb.

11. A lighting system, comprising:

a light socket configured to couple to a lighting load;

a light-dimming apparatus coupled to the light socket, wherein the light-dimming apparatus comprises:

an alternating current (AC) live input terminal configured to couple to an AC live input wire from a power source, an AC neutral input terminal configured to couple to an AC neutral input wire, an AC live output terminal configured to couple to an AC live output wire coupled to the lighting load, and an AC neutral output terminal configured to couple to an AC neutral output wire coupled to the lighting load;

a microcontroller unit comprising a plurality of wireless communication modules, one or more processor cores, and a memory;

a dimmer module configured to detect zero-crossing signals and modulate power supplied to the lighting load, wherein the dimmer module comprises:

a full bridge rectifier electrically coupled to at least the AC live input terminal and the AC neutral input terminal,

a first optocoupler electrically coupled to at least the full bridge rectifier and the microcontroller unit,

a bidirectional triode thyristor coupled to at least the AC live output wire,

a second optocoupler coupled to at least the microcontroller unit and the bidirectional triode thyristor; and

wherein the one or more processor cores of the microcontroller unit is programmed to execute instructions stored in the memory of the microcontroller unit to: receive a dimming command comprising a dimming value from another device via at least one of the plurality of wireless communication modules to dim a brightness of the lighting load, and

receive the zero-crossing signals from the dimmer module and transmit a plurality of switching signals to the second optocoupler to work with the bidirectional triode thyristor to modulate the power supplied to the lighting load to dim the brightness of the lighting load according to the dimming value.

12. The lighting system of claim 11, wherein the plurality of wireless communication modules comprise a wireless-fidelity (WiFi) module and a Bluetooth™ module.

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13. The lighting system of claim 12, wherein the one or more processor cores is further programmed to execute instructions stored in the memory of the microcontroller unit to:

receive a service set identifier (SSID) of a wireless local area network (WLAN) and a network key associated with the SSID from a client device communicatively coupled to the microcontroller unit over a Bluetooth™ communication protocol via the Bluetooth™ module; store the SSID and the network key in the memory of the microcontroller unit; wirelessly connect to the WLAN using the SSID and the network key; instruct the Bluetooth™ module to cease communication services upon successfully connecting to the WLAN; receive a dimming command comprising a dimming value from a server over a WiFi communication protocol; and receive the zero-crossing signals from the dimmer module and transmit the plurality of switching signals to the second optocoupler to work with the bidirectional triode thyristor to modulate the power supplied to the lighting load to dim the brightness of the lighting load according to the dimming value received from the server.

14. The lighting system of claim 13, wherein the one or more processors core is further programmed to execute instructions stored in the memory of the microcontroller unit to instruct the Bluetooth™ module to cease communication services undertaken by the Bluetooth™ module.

15. The lighting system of claim 13, wherein the one or more processor cores is further programmed to execute instructions stored in the memory of the microcontroller unit to:

detect that the WiFi module is disconnected from the WLAN; instruct the Bluetooth™ module to resume communication services upon detecting that the WiFi module is disconnected from the WLAN; broadcast a device name of the light-dimming apparatus to client devices within range of the Bluetooth™ module while simultaneously attempting to wirelessly reconnect to the WLAN using the SSID and the network key stored in the memory of the microcontroller unit; wirelessly reconnect to the WLAN using the SSID and the network key stored in the memory of the microcontroller unit; and instruct the Bluetooth™ module to once again cease communication services upon successfully connecting to the WLAN.

16. A method of dimming an alternating current (AC)-powered light, the method comprising:

executing instructions stored in a memory of a microcontroller unit of a light-dimming apparatus using one or more processor cores of the microcontroller unit to receive a dimming command comprising a dimming value via at least one of a wireless-fidelity (WiFi) module and a Bluetooth™ module of the microcontroller unit from another device to dim a brightness of a lighting load, wherein the light-dimming apparatus further comprises: an AC live input terminal configured to couple to an AC live input wire from a power source, an AC neutral input terminal configured to couple to an AC neutral input wire, an AC live output terminal configured to couple to an AC live output wire

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coupled to the lighting load, and an AC neutral output terminal configured to couple to an AC neutral output wire coupled to the lighting load, a dimmer module configured to detect zero-crossing signals and modulate power supplied to the lighting load, wherein the dimmer module comprises: a full bridge rectifier electrically coupled to at least the AC live input terminal and the AC neutral input terminal, a first optocoupler electrically coupled to at least the full bridge rectifier and the microcontroller unit, a bidirectional triode thyristor coupled to at least the AC live output wire, a second optocoupler coupled to at least the microcontroller unit and the bidirectional triode thyristor; and

executing further instructions stored in the memory of the microcontroller unit using the one or more processor cores to receive the zero-crossing signals from the dimmer module and transmit a plurality of switching signals to the second optocoupler to work with the bidirectional triode thyristor to modulate the power supplied to the lighting load to dim the brightness of the lighting load according to the dimming value.

17. The method of claim 16, further comprising executing instructions stored in the memory of the microcontroller unit using the one or more processor cores, wherein the instructions comprise the steps of:

receiving a service set identifier (SSID) of a wireless local area network (WLAN) and a network key associated with the SSID from a client device communicatively coupled to the microcontroller unit over a Bluetooth™ communication protocol via the Bluetooth™ module; storing the SSID and the network key in the memory of the microcontroller unit; wirelessly connecting to the WLAN using the SSID and the network key; instructing the Bluetooth™ module to cease communication services upon successfully connecting to the WLAN; receiving the dimming command comprising the dimming value from a server over a WiFi communication protocol; and receiving the zero-crossing signals from the dimmer module and transmitting the plurality of switching signals to the second optocoupler to work with the bidirectional triode thyristor to modulate the power supplied to the lighting load to dim the brightness of the lighting load according to the dimming value received from the server.

18. The method of claim 17, further comprising executing instructions stored in the memory of the microcontroller unit using the one or more processor cores, wherein the instructions comprise the steps of instructing the Bluetooth™ module to cease communication services undertaken by the Bluetooth™ module.

19. The method of claim 17, further comprising executing instructions stored in the memory of the microcontroller unit using the one or more processor cores, wherein the instructions comprise the steps of:

detecting that the WiFi module is disconnected from the WLAN; instructing the Bluetooth™ module to resume communication services upon detecting that the WiFi module is disconnected from the WLAN;

broadcasting a device name of the light-dimming apparatus to client devices within range of the Bluetooth™ module while simultaneously attempting to wirelessly reconnect to the WLAN using the SSID and the network key stored in the memory of the microcontroller unit; 5

wirelessly reconnecting to the WLAN using the SSID and the network key stored in the memory of the microcontroller unit; and

instructing the Bluetooth™ module to once again cease communication services upon successfully connecting to the WLAN. 10

20. The method of claim 17, further comprising executing instructions stored in the memory of the microcontroller unit using the one or more processor cores, wherein the instructions comprise the steps of: 15

detecting that the WiFi module is disconnected from the WLAN;

instructing the Bluetooth™ module to resume communication services upon detecting that the WiFi module is disconnected from the WLAN; 20

receiving another dimming command comprising another dimming value from the same client device or another client device wirelessly connected to the light-dimming apparatus via the Bluetooth™ module; and 25

receiving other zero-crossing signals from the dimmer module and transmitting additional switching signals to the second optocoupler to work with the bidirectional triode thyristor to modulate the power supplied to the lighting load to dim the brightness of the lighting load according to the dimming value received from the same client device or another client device. 30

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